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EXPERIMENTAL STARVATION IN MAN

Keys, Brozek, Henschel,
Mickelsen and Taylor

UNIVERSITY OF MINNESOTA
October 15, 1945

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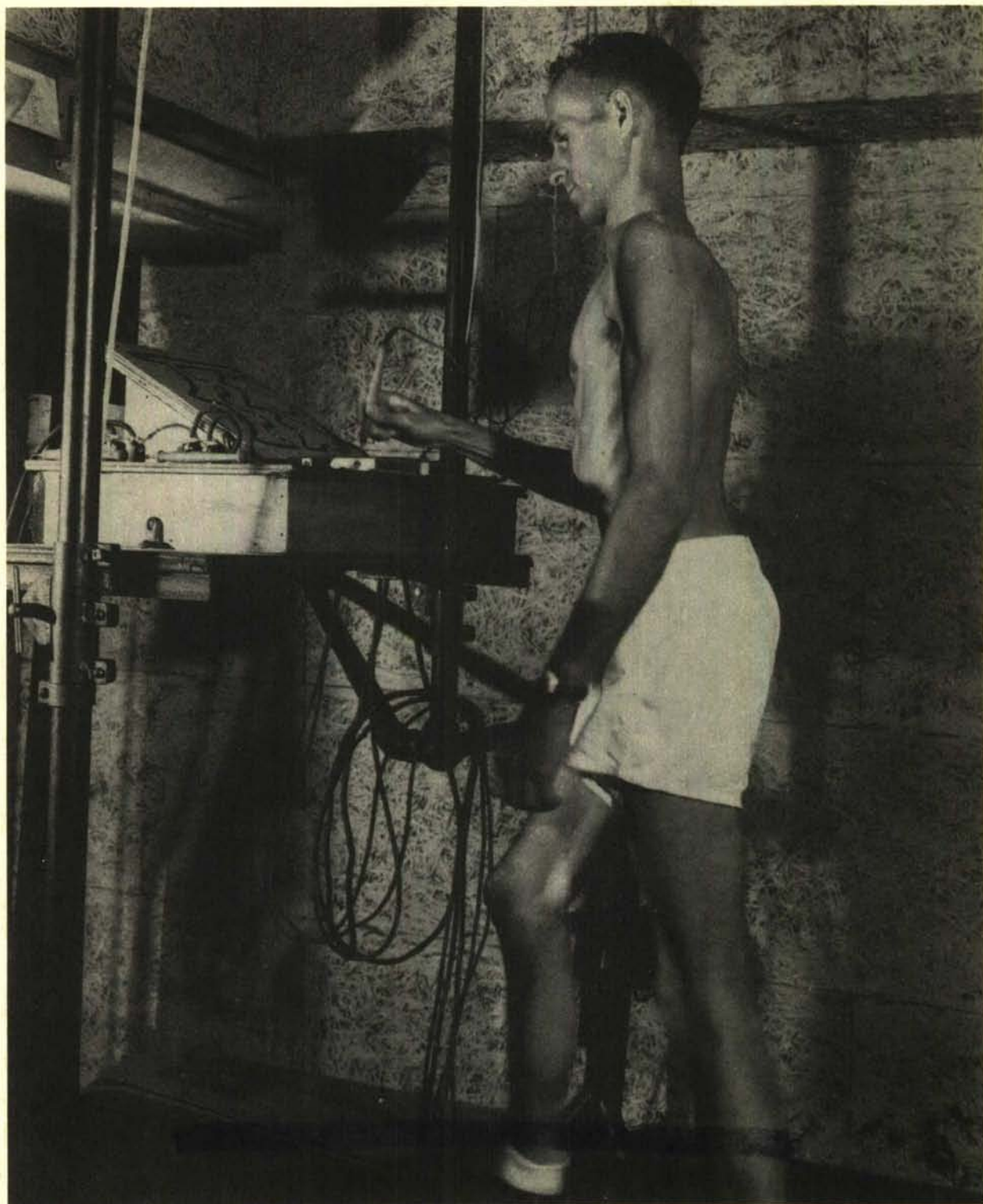


Fig. 1. PSYCHOMOTOR TESTING. Subject No. is tracing a pattern while walking at 3.5 miles per hour on a grade of 10%. The number of errors (sidewall contacts with the stylus) and their duration (total time of contact between stylus and sidewall) are recorded electrically. This is a test of coordination. See Item No. 29 in Table VI, p. 47.


EXPERIMENTAL STARVATION IN MAN

A Report from the
Laboratory of Physiological Hygiene,
University of Minnesota

by

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Olaf Mickelsen and Henry Longstreet Taylor
with the Assistance of
Ernst Simonson and Samuel Wells

October 15, 1945



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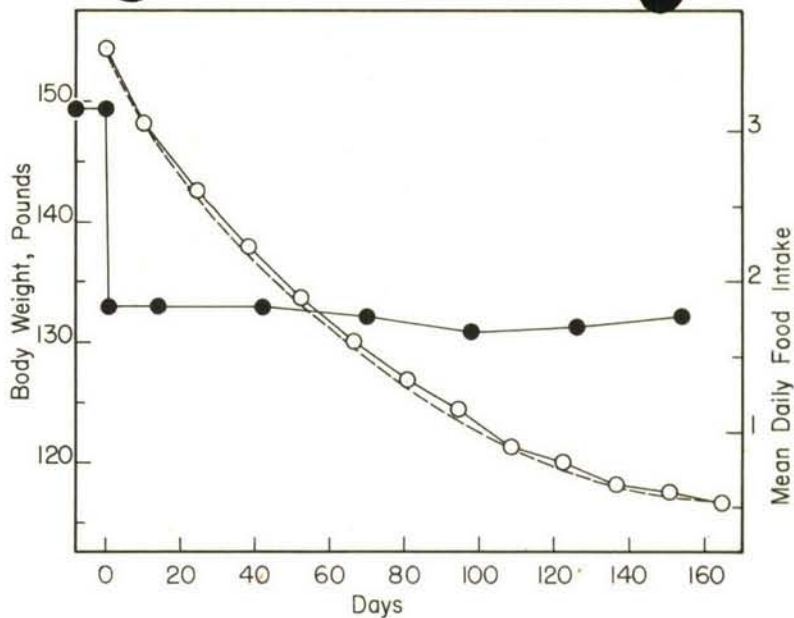


Fig. 2 AVERAGE WEIGHTS, 34 men. Predicted (broken line) and actual (solid line) body weights are shown as bi-weekly means for the entire group of 34 men. The actual food intakes, as calories, are also shown. Food intake in thousands of calories.

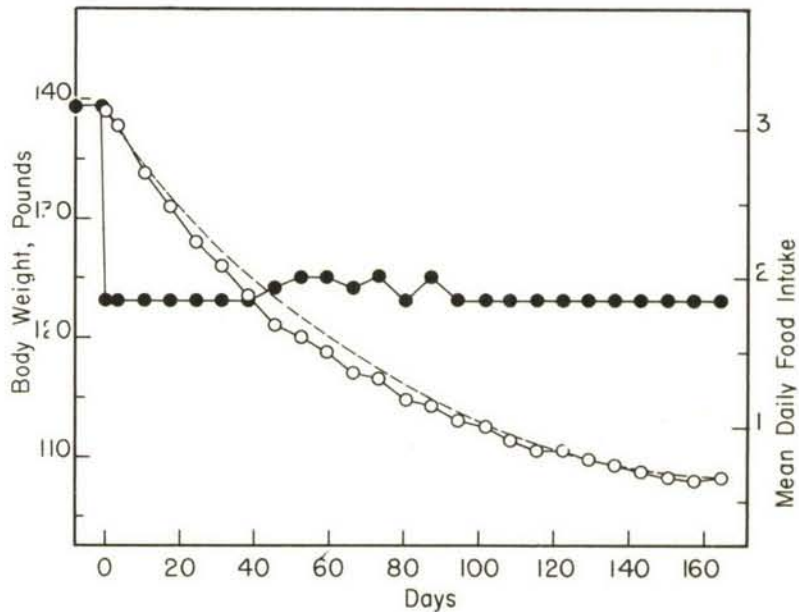


Fig. 3. BODY WEIGHT AND FOOD INTAKE. Subject No. 111. Food intake in thousands of calories.

I. INTRODUCTION

There is at present in operation at the Laboratory of Physiological Hygiene an experimental study on human starvation and nutritional rehabilitation. Thirty-four young men, previously normal and well-nourished, have completed six months of partial starvation under rigidly controlled conditions. During this time, and for the three months immediately preceeding, these volunteers were subjected to an extensive series of tests and measurements covering important physiological, biochemical and psychological functions as well as anthropometric characteristics. The character of the diet and the extent of the nutritional deficit have been calculated to be representative of moderately severe famine in north central Europe. The actual caloric intake during the starvation period averaged 1395 Cal. less than in the control period.

In the six months of starvation these men lost an average of 16.8 kg. (37.0 pounds) representing 24.0 percent of their original body weight. Individually, these losses ranged from 12.4 to 23.7 kg. (27.3 to 64.6 lbs.). These losses were associated with profound physical deterioration and psychological changes which provide a quantitative picture of the effects of prolonged starvation in man. The degree to which this picture is applicable to "natural" famine may be estimated from a study of the experimental conditions and results and from the opinion quoted on page 26-27 of this report. In general it would seem that the effects of "natural" starvation have been satisfactorily duplicated though there are some differences in detail. These have reference chiefly to the non-nutritional items of sanitation and shelter and, in the psychological area, to various emotional stresses including the by-products of political oppression.

This study comprises three phases: control, semi-starvation and rehabilitation. The present report is a preliminary summary of the operations and the findings up to the start of rehabilitation. The desirability of making the facts available for early application justifies reporting in advance of complete and detailed analysis, including statistical treatment. It is expected that a similar preliminary report on the findings in rehabilitation, including a comparison of the results with different rehabilitation diets, will be provided shortly after the conclusion of the final experimental phase, that is near the end of this year 1945. Eventually, it is planned to report the entire study in full detail in more suitable format.

II. PROBLEMS AND PURPOSES

A. The Current State of Knowledge on Starvation

The effects on man of starvation, such as occurs in war and in periods of famine, are very imperfectly known in general and are almost unexplored in terms of quantitative and functional details. Various groups working in liberated Europe are currently collecting valuable information but their findings are not yet reported and, in any case, will be rather limited because of field conditions. Present knowledge, including that still unreported in detail from the field, is restricted to the following sources of data:

1) Observations by medical and relief workers in the field. In general these merely provide inadequate data on morbidity and mortality, incomplete case reports and general impressions. Proper data are few and necessarily not very systematic. Such as they are, reports from the field suffer from paucity of quantitative measurements, absence of information as to the previous status of the persons observed, lack of data on functional characteristics, and uncertainty about the role of sanitation and the general breakdown of medical services. This is not to disparage the field work; many of the defects are inherent in field work and others arise from the limitations of scope, equipment and preparation imposed until now on nutritional studies in the field.

2) Experiments on total fasting. The classical studies were made from 25 to 45 years ago on a few persons who cannot be considered as typical or representative of a major segment of any normal population. Certainly professional

fasters and chronic food "faddists" may not be so designated. The methods used, particularly for functional measurements, are vastly inferior to those now available. The most serious objection to the data from studies on total fasts, however, is that this condition is greatly different from that of prolonged partial starvation so that few quantitative analogies can be drawn. This is very clear from a series of unpublished experiments on total fasting made in this Laboratory.

3) Animal experiments. How far these are actually comparable to human famine is dubious. In the majority of instances only total acute starvation has been studied. In any case animal experiments provide extremely few data quantitatively applicable to man and have direct little relevance to the problems of human performance and behavior. The experiments on animals have been focussed primarily on metabolic and histological questions with little attention to other problems. Very few studies on starvation in animals have been reported in recent years. It is possible new investigations using newer methods and with a broader viewpoint would be fruitful. So far the contribution to problems in human starvation is small.

4) Clinical observations. Cases of anorexia nervosa, obstructive lesions of the gastro-intestinal tract and the therapeutic treatment of obesity may offer useful similarities to the results of famine and provide a rich source of suggestive material. The intrinsic limitations are obvious but beyond this there is an aggravating absence of precise functional data from such cases.

5) Observations on refugees and rescued persons. The limitations of items 1) and 4), above, apply to a large extent but much important data could be obtained from such persons. It is unfortunate that so far only clinical case histories and casual observations are obtained in the vast majority of cases. The overwhelming and generally all-excluding concern has been to rehabilitate these persons with all means known or supposed to be beneficial. The conditions prevailing in famine and relief situations are uncontrollable and incompatible with exact and detailed measurements.

6) One major experiment on undernutrition. About 25 years ago an experiment on undernutrition of some months' duration was carried out by the Carnegie Nutrition Laboratory. Aside from the technical inadequacy of many of the methods then available, that experiment was limited to so slight a degree of undernutrition as to have limited relevance to the events in more serious starvation. The methods for control which seemed good then now appear to be far less than adequate from the point of view of proper standardization, training and motivation. Even with these numerous criticisms, however, it must be noted that much valuable information, both negative and positive, was obtained. We now take for granted many lessons then learned, particularly the indications for the adaptive powers of the human body and the difficulty of appraising performance-capacity.

B. General Problems in Human Starvation

There is a long list of questions of both practical and theoretical importance, which must be asked about the effects of starvation of the type encountered in war and famine. Among these may be noted:

1) What are the changes, and their extent and characteristics, of the basic physiological functions--heart action, peripheral circulation, respiration, temperature regulation, basal metabolism, sensory functions, digestion, excretion, reflexes, and so on? How are they inter-related? Which of these are most critical as health hazards? How may they be expected to affect or be affected by intercurrent disease?

2) What are the changes, and their extent and characteristics, in the psychological area--memory, learning capacity, reasoning power, attention, emotional stability, initiative and volition, mental endurance, imagination, and so on? How do these affect behavior, social activity, family relations, mental work, and potential community and political organization?

3) What is the course and character of metabolic adaptations to starvation? How are such adaptations related to functional and performance characteristics? Are such adaptations solely beneficial and protective?

4) What is the order in which deterioration develops in the principal areas of physical performance and capacity--strength, speed, endurance, coordination, perception? What are the rates and extents of changes in these characteristics?

5) How rapidly does significant deterioration ensue in occupational work capacity? What is the course of progression in this deterioration? What types of occupation are likely to be most affected?

6) What measurements, tests and observations may serve as useful guides or indices in the appraisal of nutritional state and performance potential of individuals and of groups in famine areas? What are the requirements for application and analysis of such measurements, tests and observations?

7) Given equal dietary limitations, what is the nature of the variability among different individuals as to general and specific deterioration? What are the bases for such variability? How may the probable response of an individual to starvation be estimated or predicted?

Any and all reliable data bearing on the foregoing questions, directly or by inference, should have immediate application to practical problems of planning and administering food relief, the evaluation of industrial potentials, the estimation of the political repercussions of famine and the establishment and administration of medical operations.

C. The Purpose and Nature of the Present Experiment.

The general purpose of the present experiment was to provide a detailed and quantitative description of some major effects of starvation which would have maximal value in formulating answers to such general questions as are listed above.

It was not to be expected that full and direct answers to all, or even a majority, of these questions would emerge from the experimental study reported here. The plan did provide, however, for objective recording of basic data in the major areas of function so as to provide at least a basis for reasonable inferences. In general these provide measures or indices of the performance potential in "natural" starvation situations. The simultaneous measurement of many functions also provides a basis for the discovery of interrelations between the several functions in starvation. What may be the expression in actual situations of these functional characteristics and alterations is dependent on many factors, chiefly sociological and psychological. In spite of this limitation, it is believed that the present studies have considerable predictive value and at least define the major possibilities.

It is not intended here to set forth detailed reasoning to validate the particular measurements and observations as answers one-step-removed, to the broader questions listed above. In general the attempt has been to measure the functions themselves in the most direct manner.

The physiological and certain psychological functions, then, are the central theme. These are to be examined against the background of the nutritional state. The latter is indicated by chemical analyses, the anthropometric changes, notably body weight, and by the known food intakes and the duration of the caloric deficits. In a somewhat different category are the personality and emotional characteristics. To some extent these are deduced from performance and overt behavior but to a large extent they are estimated by indirect means which presumably allow an estimation of the general nature, if not the details, of potential response to different types of personal situations.

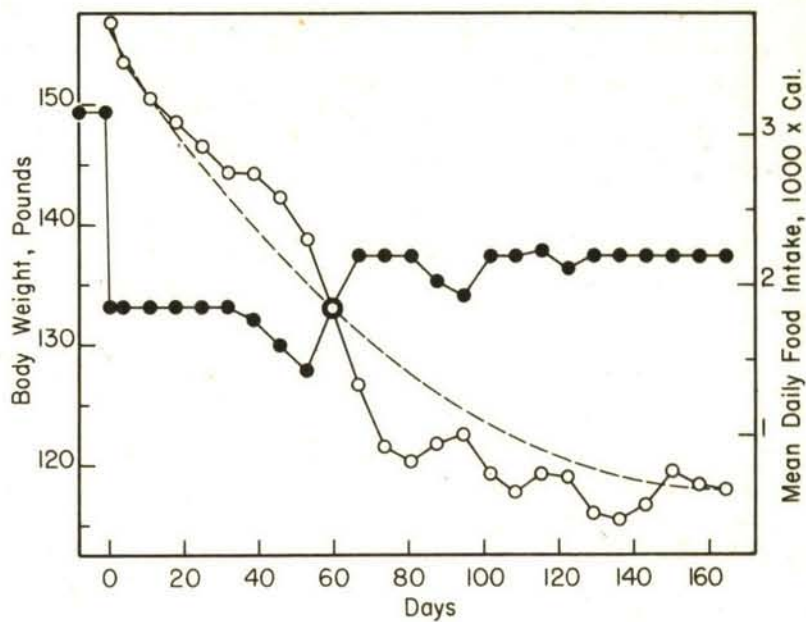


Fig. 4. BODY WEIGHT AND FOOD INTAKE. Subject No. 29.

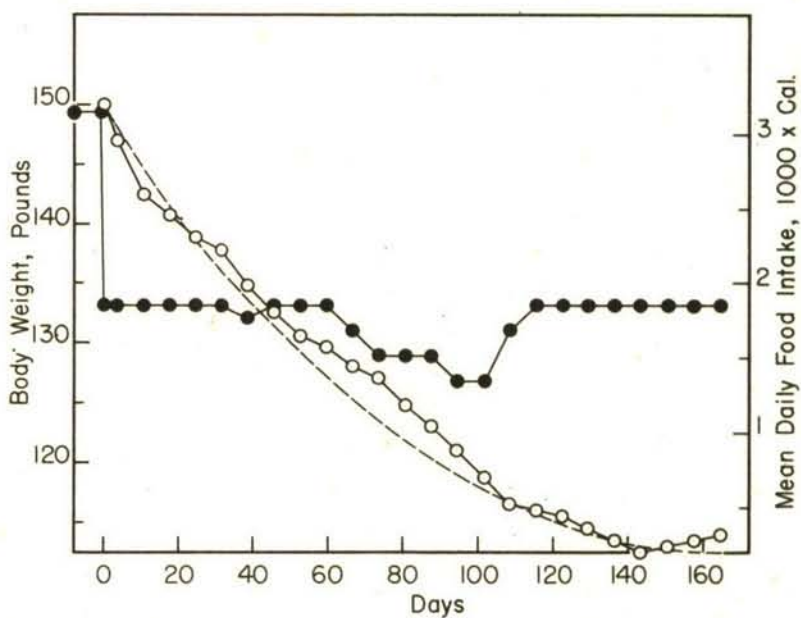


Fig. 5. BODY WEIGHT AND FOOD INTAKE. Subject No. 104.

III. SUBJECTS, DIETS AND PROGRAM

A. Subjects

The subjects in this study are all conscientious objectors who were selected from volunteers in Civilian Public Service. Their transfer to this project was endorsed by the Committee on Medical Research of the Office of Scientific Research and Development and was authorized by the Selective Service System. Before volunteering all men were completely informed as to the purposes, methods of operation, rigors and dangers involved.

Selection was made on the basis of medical and psychological examinations, personal interviews and the recommendations of responsible persons. Each man was certified by one of the several Service Committees of the churches as being desirable because of his special interest in relief problems as well as his personal integrity. The men finally selected were drawn from 25 Civilian Service installations; their permanent homes are in 16 states. Each man guaranteed his perseverance in the project until completion, regardless of possible release from his status in Selective Service. The principal medical and psychological requirements were: freedom from significant organic disease and defects, unimportant previous medical history, emotional stability and acceptable personality.

This group of subjects ranged in age from 20 to 33 years, in height from 168.6 to 192.4 cm. (66.4 to 75.7 inches), and in initial weight from 61.2 to 82.4 kg. (135.0 to 181.7 pounds). They represented a wide range of anthropometric types, athletic habits, occupation or occupational interest, physical "fitness" and general intelligence. The majority are college graduates or had been college students at the time of induction.

Many of the initial characteristics of these men, after several months of standardization in this Laboratory, are indicated in the tables contained in the present report. They averaged slightly above the general mean for Selective Service inductees in height and weight and considerably above average in general intelligence as indicated by the Army Classification Test and Thorndike's "C. A. V. D." Test. Their average basal metabolism was somewhat low in comparison with the Mayo Clinic standards (Boothby and Berkson), but close to the normal mean for young men measured in this Laboratory. A slow basal pulse is also characteristically recorded here and this group was no exception. The height-weight ratio, vital capacity and blood hemoglobin concentration were close to ordinary normal averages. The blood plasma protein concentration tended to be somewhat below normal averages, either as published elsewhere or as obtained here.

It may be presumed that the long-time previous nutritional history of these men was not worse, and probably was considerably better than the national average; this follows from a consideration of their family background. On the other hand the somewhat haphazard dietaries at many Civilian Public Service installations suggests that just previous to arrival here many of these men had subsisted on diets which were not superior to the general average of the country. No definite stigmata of nutritional deficiency were observed on arrival or in the control (standardization) period before starvation.

B. Program

The program was designed to provide a reasonably constant "occupational" activity with periodic exhaustive tests and measurements covering the major areas of function as they enter into normal life and behavior. The initial control period of 3 months allowed standardization of the several tests as well as of diet, activity and personal living conditions. The semi-starvation period of 6 months was calculated to bring about an average loss of gross body weight amounting to 25% of the control weight.

All of the men were continuously resident in the Laboratory and did not leave the building alone. The "buddy" system of mutual chaperonage allowed for attendance at certain university classes and other functions, limited outdoor

Fig. 6. STANDARDIZED ACTIVITY. Four subjects on the large treadmill walking at 3.5 m.p.h. and 10% grade. This was a standard weekly exercise and a standard condition for studying metabolism and circulation in "aerobic" work.



recreation, church attendance and social functions.

Walking on the treadmill and over set outside courses helped maintain standardization of physical activity. Each man had a fixed responsibility of assistance in some phase of the housekeeping or laboratory operations; this assigned non-subject work averaged about 15 hours a week except toward the end of the semi-starvation period when strict adherence to such schedules became impossible because of weakness and apathy. A study program continued throughout the entire period; this occupied about 25 hours a week except toward the end of semi-starvation when this program likewise largely succumbed to the effects of starvation. This study program is described in a subsequent section of this report. Provisions for recreation and the pursuit of personal hobbies and interests within the Laboratory mitigated the rigorous regimen and helped to maintain the possibilities of a reasonably normal existence. The fact that all of the men were personally interested and convinced as to the importance of their contribution was of great value.

The program of tests and measurements provided for repetitions during the control period to ensure accuracy of the evaluation of the pre-starvation state and functions. The effects of semi-starvation were estimated to a large extent from the results of exact repetitions of these measurements in 2 general periods: 1) the "mid-point" of starvation, here taken to be the 12th and 13th weeks, and, 2) the end of starvation (23rd and 24th weeks). Other measurements, selected because of convenience and presumed importance in the starving state, were repeated at more frequent intervals. In all tests and measurements the greatest care was taken to guarantee absolute constancy of conditions. These conditions included time of day, sequence and details of activities and tests, temperature, humidity, lighting, air movement, clothing and psychological "atmosphere".

Body weight was recorded daily and each man's predicted and desired weight change was checked weekly against his actual weight. Each man kept a diary in which were recorded his feelings, subjective impressions and events which might be of interest or significance. Frequent intimate personal interviews with Staff members and other psychiatrists and psychologists amplified the psychological information and assisted in maintaining morale and mental well-being.

C. Extent of Starvation

There are numerous indications from observations in famine areas and from animal experiments which indicate that starvation which is represented by a weight loss of some 25 to 30% of the original body weight is about as much as can be produced with reasonable safety in 6 months in persons not obese initially. This value of around a quarter of the body weight lost is fairly characteristic of the person who has been severely starved for many months but not for years and who is not irretrievably cachectic. Reports of greater losses are frequently complicated by dehydration and previous relative obesity.

Such information as is available on the rate of weight loss in famine conditions suggests that the rate decreases steadily and frequently a relative plateau is reached at something like 70 or 75% of the initial weight. Finally, it is clear that the stress of starvation is related to the relative initial obesity and a moderately thin person may suffer as much general deterioration with a weight loss of 20% as a somewhat overweight person who loses 30%.

These considerations determined the selection of the extent, rate and individual adjustments in weight changes which were established as goals and prediction curves in the present study. The "ideal" relation between body weight and the course of semi-starvation was believed to be that in which the rate of weight loss would change at constant rate to reach zero change at the end of 24 weeks. At that time the average weight loss should be 25% of the initial body weight. Though none of the subjects were initially grossly obese nor strikingly thin, there were considerable individual differences and in order to approach relative constancy of starvation stress, the individual goals were set at from 21 to 28% weight loss. For this purpose "ideal" or "normal" height-weight tables, adjusted for age and body type, were used.



Fig. 7. RELAXATION, FOURTH MONTH OF SEMI-STARVATION. De-
veloping emaciation is evident in a casual glance at a group
while sunbathing.

Mathematically, the general curve required for weight versus time is represented by a parabola with vertical axis and zero slope at 24 weeks. The equation is: $W_x = W_f + K(24-t)^2$, where W_f is final weight, t is time in weeks and W_x is weight at time t . If W_0 is initial weight and G is the desired total per cent of weight loss, then the equation can be written: $W_x = W_0(100-G)/100 + K(24-t)^2$. For each case the constant K is obtained: $576 K = W_0(G)/100$. The foregoing method was used to obtain the prediction curves for each man, such as shown in Figures 2, 3, 4 and 5.

D. Diets

The basic diet for the control (standardization) period consisted of a series of menus devised to be calorically adequate and reasonably "normal" with regard to variety, food items and specific nutrients as eaten under good economic circumstances in the United States and northern Europe. The character of this diet may be gauged from the representative menus and the nutritional analyses given in the tables included in this report. On the average this control diet provided 3150 Calories, 34 per cent of which were from fats, and included 110 grams of proteins.

Quantitative adjustments in the control diet were made, on an individual basis for the body size and relative obesity. These were established on a set rule of allowances for body weights, modified to provide correction for initial deviations from normal averages for height-weight ratios adjusted to body type. During this control period the objectives were to arrive at an estimate of caloric requirements in the set activity regimen, to maintain balance in individuals who did not depart widely from "ideal" weight, and to bring the unduly thin and fat members of the group closer to "ideal" weights. The weight change from the beginning to the end of this control period averaged -1.84 kg. (4.05 pounds), the extremes being -5.68 kg. (12.5 pounds) and +3.8 kg. (8.5 pounds).

The basic diet for the semi-starvation period consisted of 3 menus repeated in rotation. These menus, and their nutritional analysis, are given in Tables III and IV. The major items were bread, potatoes and cereals, with considerable amounts of turnips and cabbage. Only token amounts of meats and dairy products were provided. As nearly as possible this diet was devised to represent the foods, in kind and proportion, which characterize European famine conditions. This basic diet supplied an average of 1850 Cal. of which fats accounted for 10.8 per cent (22 grams). It provided 49 grams of proteins, almost entirely of vegetable origin. The content of calcium, phosphorus, iron and the major vitamins proved to be relatively good, or at least more satisfactory than might be guessed at first sight.

It was planned at the outset to attempt to produce a roughly equivalent starvation stress in each of the subjects. Even at the end of the control period, there were substantial individual differences in relative obesity so it was believed that the proportion of body weight to be lost in semi-starvation should be set on an individual basis. The dietary arrangements provided for such adjustment, and for compensation for the differences in body size. All men received the same amounts of all items save bread and potatoes; these two foods were basis for all individual adjustments. Weekly adjustments were made according to the weight records of the previous week as compared with the individual prediction curves. In general, this type of empirical adjustment did not change markedly from week to week and it appeared that the original calculations as to the course of weight loss were reasonably successful, though the question was complicated by the occurrence of edema and increased interstitial fluid volume.

After allowing for all individual adjustments in the diet, the average individual daily intakes averaged, for successive months, 1) 1834, 2) 1833, 3) 1766, 4) 1661, 5) 1694, 6) 1764 Calories. These caloric intakes may not seem drastically low in view of popular reports from Europe of rations of 500 to 800 Cal. daily. There are several considerations. The present intakes were exact actual values; no such accuracy obtains with the reported very low values in Axis-occupied Europe. The European values are, in general, family or community

averages estimated from housewives' recollections of how bad conditions were at the worst; presumably they are to be compared with "normal" averages for the same groups. The latter figures are of the order of 2500 Cal., the values for young men being considerably higher than those for the other members of the family or group. It must be believed that under severe general rationing there would be a similar disproportion between individuals. It must be noted that the present subjects changed from a control average of 3150 Cal. to a semi-starvation average of 1755 Cal.; this represents a potential deficit of 1395 Cal. per day.

IV. TESTS, MEASUREMENTS AND OBSERVATIONS

A. General

In all tests and measurements efforts were made to achieve great uniformity of conditions as well as technical accuracy of measurement. An integral part of the program was the use of detailed statistical procedures both in planning and in operation of the experiment. The attempt was made to obtain the measurements in such a way as to allow evaluation of reliability, intrinsic error, inter- and intra-individual variation, and trend. It is believed that the full value of this feature of the work will be most apparent in the analysis of the data during rehabilitation but proper objective statistical analysis of the data in the control and semi-starvation periods obviously had many advantages. Such statistical treatment of data from other experiments in this Laboratory provided a basis for the selection of many of the methods used in the present study and for decision as to the mode of application of those methods. The major statistical method used was that of the analysis of variance.

A number of tests and measurements were developed and standardized for the first time in the course of the semi-starvation period. For these no pre-starvation control data exist, of course, and it will be necessary to use the values obtained after 3 to 5 months of rehabilitation for "control" comparison with the results in semi-starvation.

B. Anatomy, Anthropometry and Histology.

Gross anatomical measurements included standing and sitting height, circumferences of the chest, abdomen, upper arm, thigh and calf, and the following diameters: bi-acromial, bi-cristal, bi-trochanteric and bi-humeral. The latter (diameters) served primarily as useful indices as to the repeatability of the technical processes of measurement. Besides the regular daily weighings, the density of the whole body was measured by weighing in air and totally immersed in water. A photographic record under fixed lighting and distance and against a rectangular reference grid, was made in the nude in frontal, back, right and left side views.

Histological information was obtained at the end of semi-starvation from skin biopsies taken from 6 of the subjects. These were made and analysed by Dr. Hamilton Montgomery of the Mayo Clinic. Other information on the microscopic features of tissues was obtained from regular hematological examinations and from sternal marrow biopsy. The latter was performed by Dr. Dorothy Sundberg on 5 subjects.

Estimations of the mineral density of the bones were made by quantitative measurements of X-ray opacity calibrated against ivory standards. These studies were made by Dr. P. B. Mack and Mr. Hugh Trapp of Pennsylvania State College at the end of starvation and are being repeated during rehabilitation.

The estimation of total extracellular fluid volume was made by means of the thiocyanate dilution method.

C. Chemistry

The chemical studies covered nutritional analyses of all diets, and analyses of blood and excreta. The chemical program was designed to throw the most



Fig. 8. ANTHROPOMETRIC PHOTOGRAPHS of subject No. 29 A, B, and C were taken at the end of the control period when the body weight was 156 pounds. D, E, and F were taken at the end of six months of semi-starvation when the body weight was 118 pounds.

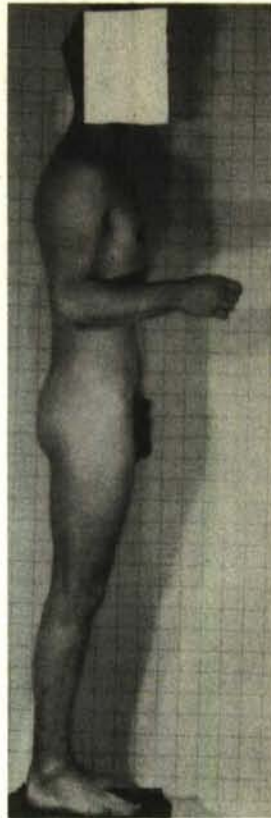


Fig. 9. ANTHROPOMETRIC PHOTOGRAPHS of subject No. 20. A, B, and C were taken at the end of the control period when the body weight was 143 pounds. D, E, and F were taken at the end of six months of semi-starvation when the body weight was 106 pounds.

light on the metabolic processes and the biochemical bases of function without imposing an insuperable burden of analytical work. Included were such obvious items as blood hemoglobin, blood sugar and plasma protein, as well as energy metabolism in basal rest and in fixed work. During several periods studies on nitrogen metabolism were made on a small selected group of the subjects. In order to provide data on vitamin metabolism the plasma ascorbic acid and the urinary excretion of thiamine, riboflavin and pyrimidine ("pyramin") were measured.

The metabolism in anerobic work, where near exhaustion was produced in brief running, was examined in some detail by means of measurements of oxygen debt, blood lactate and blood pyruvate.

The detailed analysis of the plasma proteins by the Tiselius electrophoretic method was greatly impaired by the loss of many plasma samples in a brief but disastrous power failure in one of the low-temperature refrigeration cabinets.

D. Physiology

We consider the physiological studies to comprise work and performance tests in the psychomotor area as well as the more restricted physiological measurements. For convenience, it is desirable to treat this whole large field as a series of functional areas.

The heart was studied by means of electrocardiography, roentgenkymography and pulse rate measurements in rest, in work and in recovery from exertion. The cardiac function is one factor in the total circulation which was studied by means of measurements of arterial and venous blood pressure, the blood and plasma volume (Evan's blue dye and hematocrit), and the response to vertical posture (tilt table).

The capacity for simple physical work was estimated primarily from experiments on the motor-driven treadmill. These included both "aerobic" and "anerobic" work tests, the Harvard "Fitness" test and the measurement of the maximal oxygen transport by the blood. In the latter measurements several work intensities were used, all exceeding the steady state level. Additional light on work capacity is afforded by the measurements of respiratory efficiency and total energy efficiency in work.

Simple muscular strength was estimated by hand-grip and back-lift dynamometers and by measurements of the maximum speed of knee lift with and without added weight. Maximum knee-lift force was also measured with a special dynamometer.

Speed and coordination were estimated by maximal rate of tapping, by number and duration of errors in pattern tracing, by the gross body reaction during work, by the ball and pipe test, and by postural stability in the upright position (ataxiometer). This battery of tests and measurements has been extensively studied in this Laboratory so that training and practice requirements to reach stable plateaus are properly known.

Vision was studied as visual acuity at both high and low illumination. Hearing was measured at 5 different frequencies with the audiometer. Flicker fusion frequency tests provided a measure of what appears to be primarily a cortical aspect of vision.

Other physiological measurements included vital capacity, gastric emptying time, and gastric acidity (basal and after histamine).

E. Psychology

The psychological studies were devised to provide objective information on the intellectual functions, on emotion and on personality. The capacity for intellectual performance was assessed from Thurstone's Test of Primary Mental

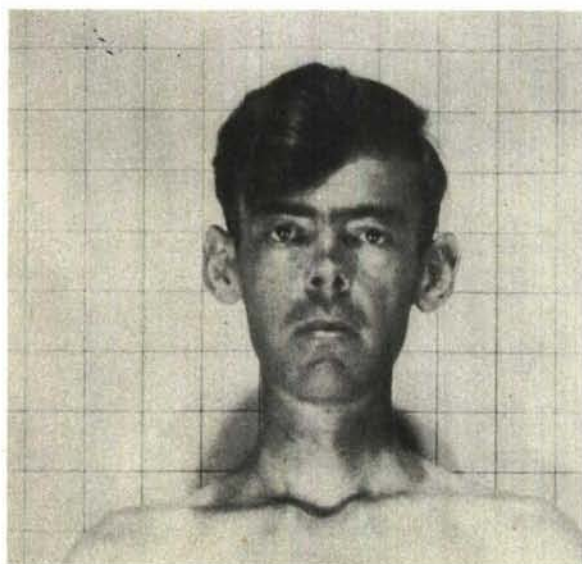


Fig. 10. FACIAL APPEARANCE of subject No. 12 A and B were taken at the end of the control period. C and D were taken at the end of six months of semi-starvation.

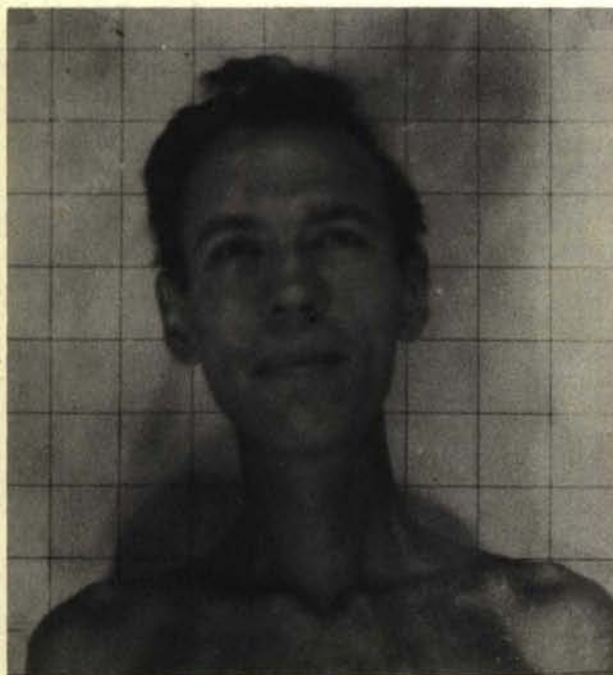
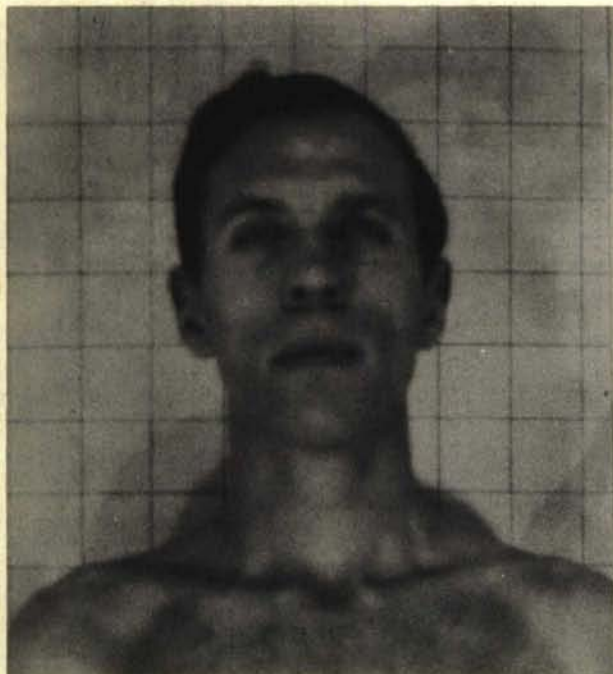


Fig. 11. FACIAL APPEARANCE of subject No. 29. A and B were taken at the end of the control period. C and D were taken at the end of six months of semi-starvation.

Abilities, Thorndike's C.A.V.D. Test (sentence completions, arithmetic, vocabulary, directions) and a repeatable factor battery especially developed for these studies. The factor battery covered space perception, memory, verbal fluency, speed of perception, multiplication and inductive reasoning. It should be noted that both "speed" and "power" tests are represented in the test list.

The "impersonal" objective methods used in evaluating personality included the Hathaway-McKinley Minnesota Multiphasic Personality Inventory, the Guilford-Martin Personality Inventories, and the Rorschach Ink Blot Test. These methods were powerfully supplemented by the use of regularly kept diaries, complaint questionnaires, scheduled and informal personal interviews, and the constant opportunity for personal contact between staff and subjects. Besides interviews conducted by the regular Staff members, Dr. B. C. Schiele interviewed many of the subjects from time to time, particularly at times of personal stress.

F. Clinical and Other Observations

Regular physical examinations, conducted by both Staff and outside examiners, covered the ordinary items with particular attention paid to the skin, mouth and eyes. Special examinations of individuals were conducted on the basis of personal complaints and whenever unusual or rapid changes were suspected. Close daily contact over many months allowed alterations in appearance and behavior to be noted quickly.

The dental studies included full-mouth roentgenograms, careful inspection of the state of the gums and recordings of number, location and extent of all carious developments. These systematic observations were carried out by Dr. Tegner at intervals of several months.

V. RESULTS

A. General Operations

In general, the program proceeded in close accord with the plan and it was possible to adhere to the rather difficult conditions selected. The arduous and technically demanding program of tests and measurements was maintained in a satisfactory manner. Most of the tests and measurements were made in duplicate and excellent checks were obtained in the great majority of cases. The morale of the subjects continued to be surprisingly high for the first few months of semi-starvation; during the last two months of this period accelerating physical debility was associated with progressive apathy and depression. Toward the end non-subject project work was frequently done perfunctorily or skipped, ordinary social relations dwindled to almost zero and the educational program sagged badly.

The weight losses followed the desired pattern very closely on the average but individuals developed more pronounced irregularities and variations as edema became more prominent. In a number of cases marked alterations in the appearance and loss of edema were reflected in relatively large changes in weight--several pounds a day--over periods of some days. The empirical adjustment of individual diets became more troublesome and more uncertain in the face of these irregularities; a by-product was the necessity for lengthy explanations to individual subjects as to why their diets should not be increased upward or at least not decreased.

It was fortunate that illnesses and accidents did not interfere with the operations. In a few cases colds were troublesome and in two of these a low-grade respiratory infection persisted for some weeks but eventually cleared up without having necessitated any real break in the regimen. One man was removed from the unit because of an unexplained urinary tract disorder. In the second month of semi-starvation one man was dismissed for psychological reasons. Several other men had periods of serious emotional stress which, however, responded to simple psychiatric measures.

B. General Appearance and Clinical Observations

At the end of semi-starvation the men were examined clinically by Doctors V. H. Sydenstricker, Russell M. Wilder, Col. John Youmans and Major Marvin Corlette, as well as by the Staff of the Laboratory. In these examinations attention was concentrated on those features generally believed to be most indicative of nutritional deficiency.

In general appearance at the end of semi-starvation all men were obviously much undernourished and even emaciated but the extent of the changes was apparent only to those who had examined these men before starvation. The facial color was sallow and pallid. More than half of the men exhibited a patchy brownish pigmentation most frequently distributed around the mouth and around the eyes in a "spectacle" effect, but occasionally such pigmented patches were seen elsewhere on the body. Almost all of the men exhibited a slight or moderate degree of cyanosis, most conspicuous in the nail beds but frequently seen in the lips as well.

Increased vascularity of the cornea, and other changes in the eyes which are frequently reported in nutritional deficiencies, was not seen in this group. In contrast, the corneas were white and avascular to an extent which made them appear conspicuously abnormal. The comparison was made with the appearance of unglazed white porcelain, that is the scleral conjunctivae where dead white and lifeless. Even application of soap solution provoked almost no reddening.

Lesions of the lips, tongue and gums were entirely absent in 23 men, minimal or questionable in 11 and more definite in 2 men. These latter exhibited only mild fissuring or denudation at the angles of the mouth and, in one man, increased fissuring and reddening of the tongue. The minimal or questionable lesions were primarily thinning of the epithelium of the lips. Aside from the frequent appearance of dental impressions ascribed to lingual edema, the tongues were all substantially normal except in one man as noted. Gingivitis was not present; the gums were pallid and bleeding could not be elicited by pressure. In some of the subjects firm pressure with a flat-tipped stylus at the bases of the interdental papillae indicated what was believed to be moderately increased sensitivity. Definite recession of the interdental papillae was noted in 7 men but this was not proved to be of recent origin.

The skin was dry, cold and thin to the touch and, in many cases, was roughened in one or more large areas. Follicular pouting and hyperkeratosis, mostly of slight degree, was suggested in 25 of the men. In a few cases there was plugging and pigmentation of follicles but generally the condition was represented only by a "permanent gooseflesh" appearance. Skin biopsies taken from 6 of the men showing more pronounced changes disclosed only relatively slight histological abnormality.

Edema began to be apparent in a few men within the second month of semi-starvation and eventually appeared at one time or another in almost all of them in many of whom it was rather labile, increasing and receding at intervals of days or weeks. In most cases visible and palpable edema was confined to the face and lower legs in grades 1, 2 or 3 on a scale of 0 to 4. A few of the men had definite accumulations of fluid in the knee joints which was sufficient to occasion some difficulty in walking in one man. No ascites could be demonstrated at any time.

Anesthesia or hyperesthesia did not appear and there was no deep muscle tenderness nor impairment of vibration sense.

Nineteen of the men showed definitely decreased patellar reflexes; in eleven cases the reflex could be obtained only by reinforcement and in one case even reinforcement failed. Thirteen men had decreased achilles tendon reflexes; in 6 reinforcement was required to elicit any response and no response could be obtained in 2 men even with reinforcement. These changes in reflexes were uniformly symmetrical.

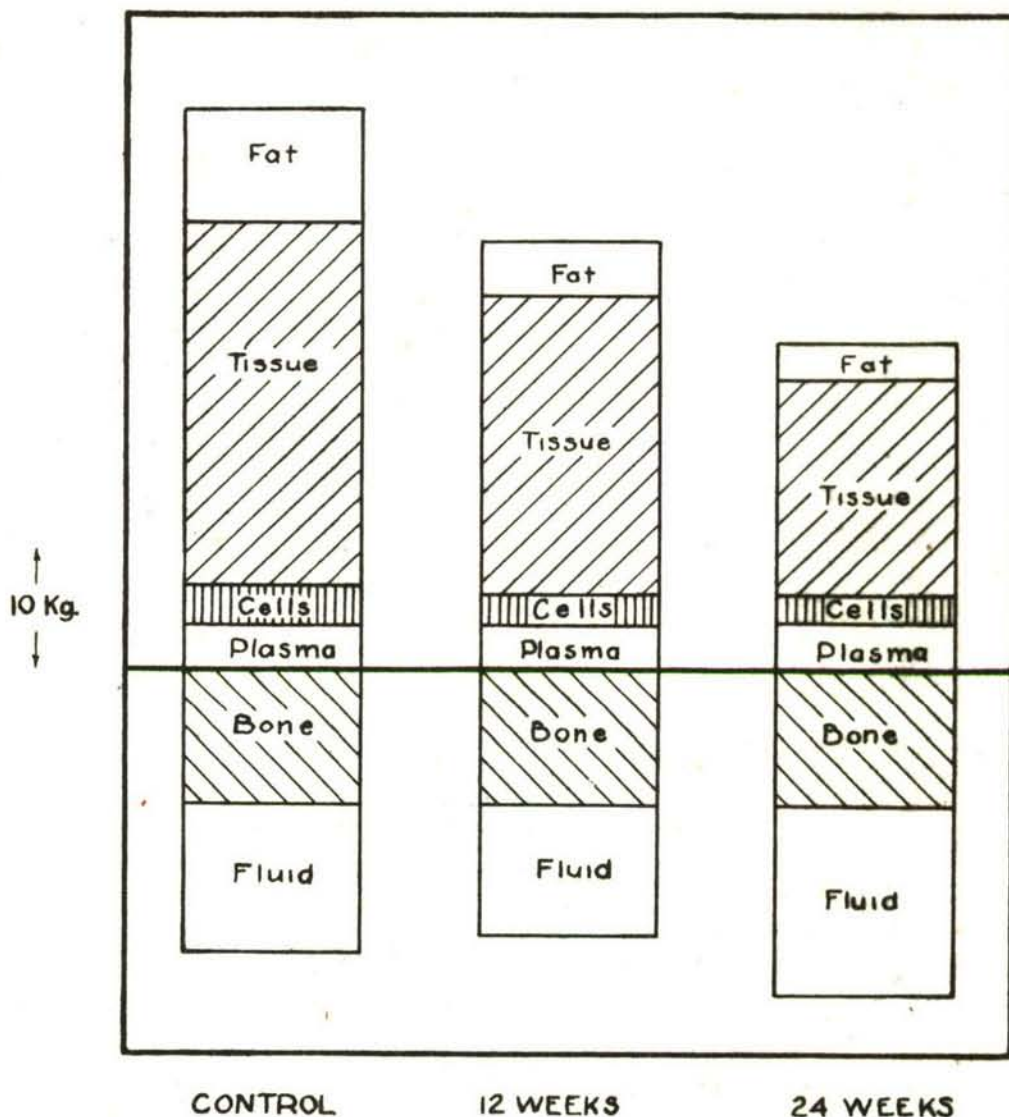


Fig. 12. WEIGHT COMPARTMENTS OF THE BODY. Total weight and weights of body compartments. Plasma estimated by the dye method; blood cells from plasma volume and hematocrit; extra-cellular fluid from the thiocyanate method; fat from the specific gravity; bones estimated from Mitchell, H. H., T. S. Hamilton, F. R. Steggyerda and H. W. Bean (J.B.C., vol. 158, p. 625, 1945) The fluid volume is the extra-cellular volume minus the blood volume. Average values for 7 men.

A curious finding was what seemed to be unusually frequent creaking of the joints in such motions as squatting and stepping up on a chair. Among other miscellaneous items may be mentioned the general lifeless and "staring" appearance of the hair and frequent marked atrophy of the supraspinatus muscle.

Other clinical items are reported in subsequent sections of this report. It was clear that evidence of vitamin deficiencies was slight and equivocal. The skin peculiarities might be related to a deficiency of vitamin A but the inanition and very low fat intake may have been responsible. The dietary vitamin A was low but not extremely so.

The picture was strikingly similar to what has been seen recently in liberated German concentration camps and in occupied Europe. The following statement by Major Marvin Corlette, M.C., is of interest in view of his extensive experience at the time of liberation in Northwestern Europe.

"In mid July 1945, it was my pleasure in company with Colonel John B. Youmans, Director, Nutrition Division, SGO, and Dr. V. P. Sydenstricker, Professor of Medicine, University of Georgia, to visit the Laboratory of Physiological Hygiene under the direction of Dr. Ancel Keys at the University of Minnesota. The purpose of this visit was to observe a group of 34 conscientious objectors who had been on semi-starvation diets of about 1600 calories for the preceding six months. These men had been on a preliminary 3 months standardization period, prior to their starvation, during which time their caloric intakes and energy expenditures were equilibrated at about 3300 calories. During the starvation period, the energy expenditures of the subjects had been kept at the 3300 calorie level.

"The picture presented by these men was a most striking one exhibiting as they did an average weight loss of about 40 pounds. Most had gaunt pinched faces and the peculiar sallow color that those of us who had seen the concentration camps in Western Europe had learned to associate at a glance with starvation. At least 65% of the subjects had demonstrable dependent edema and many had brownish pigmentation of their skin. Practically all exhibited a pronounced sinus bradycardia with resting pulse rates in the low thirties.

"These were the salient clinical features of the picture we saw at Minneapolis, and it very closely simulated the picture of semi-starvation seen in Western Holland as well as in some of the German concentration camps in the early spring of 1945. Except for the absence of filth and secondary skin infections in the experimental subjects, it appears that the fundamental clinical pattern of partial starvation as we observed it in Europe has been duplicated."

The general behavior and manner of these men was instructive, particularly to those who saw them frequently under all the conditions of daily life. As starvation progressed they became more and more silent, apathetic and immobile. Movements were slow and restricted; stairs were mounted one at a time and the men sat or stood leaning against a wall while waiting. In discussion there was no evidence of confusion of thought or difficulty of expression but the attitude was frequently irritable and morose. Trivial incidents were productive of exaggerated annoyance and complaint. Favorite topics of conversation were food, farming and rural life, a fact which was bitterly resented by some of the men.

C. Complaints

Complaints were recorded systematically each month and further information was elicited in personal interviews held about every six weeks. Excessive appetite and hunger plagued all of the men increasingly throughout the entire 6 months. These items of complaint were exceeded in frequency and intensity only by that of tiredness and fatigue. Muscle soreness, apathy, general irritability inability to concentrate, depression, dizziness, lack of ambition, moodiness, sensitivity to noise, were very prominent complaints which progressively increased. Muscle cramps were somewhat troublesome in the last 2 months. Nausea, fainting, and a sense of apprehension were trivial sporadic and non-progressive

complaints. Each of these complaints was self-rated on a scale of 0 (normal) to 5 (extreme). The average rating score at the end was, for example, 3.5 for "tiredness", 1.8 for apathy, 1.3 for dizziness.

All of the men continually complained of feeling cold and even in the warm weather of July most of them wore heavy clothes. The conclusion was clear that any lack of heat in the building would have produced bitter suffering. Another frequent complaint was the sensation of being "old". It was difficult to discover exactly what was meant by this expression but apparently the sensation of weakness, depression, lack of ambition and absence of libido combined to convey a sense of old age.

One complaint referred most directly to the actual loss of body tissue. While the men did not greatly mind their clothes not fitting, they did object to the sensation of sitting on ordinary unpadded chairs. Pillows, blankets and all kinds of padding material were collected and pressed into service. A converse complaint was restricted to a few men who suffered from overly tight shoes because of excessive edema.

Aside from hunger pains in all men and some gastritis in a few, there were no important complaints referable to the gastro-intestinal system. While bowel movements tended to decrease in frequency there was little or no constipation. It should be noted that the diet had a relatively large bulk and residue.

A number of men were bothered by vivid dreams, particularly dreams of breaking the diet with attendant great remorse. Sleep was highly variable but the average result seemed to be a need for more than the previous amount, though this was often broken up in several portions. Night-time insomnia was frequent but was not considered to be a serious complaint.

Complaints about food and the diet were confined to the amount of food and, far less important, to accidental delays in serving.

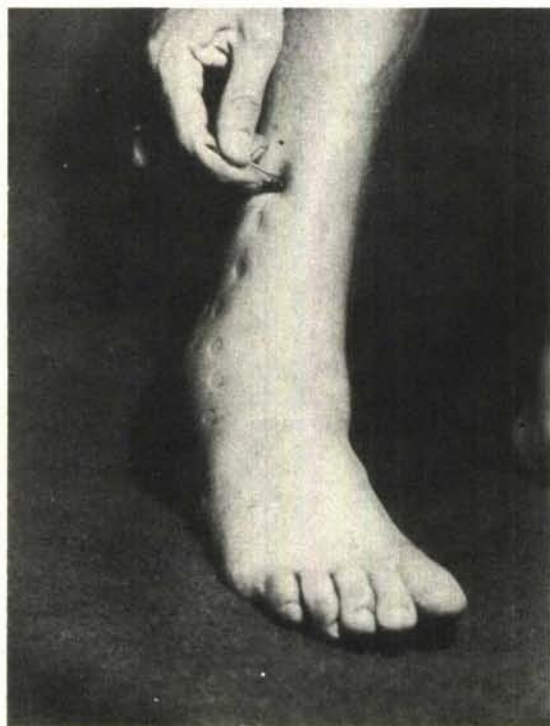


Fig. 13. PHOTOGRAPHS TAKEN AT SIX MONTHS of semi-starvation showing extensive ankle edema in subject No. 130 and swelling of the knee due to fluid in the joint in subject No. 20.

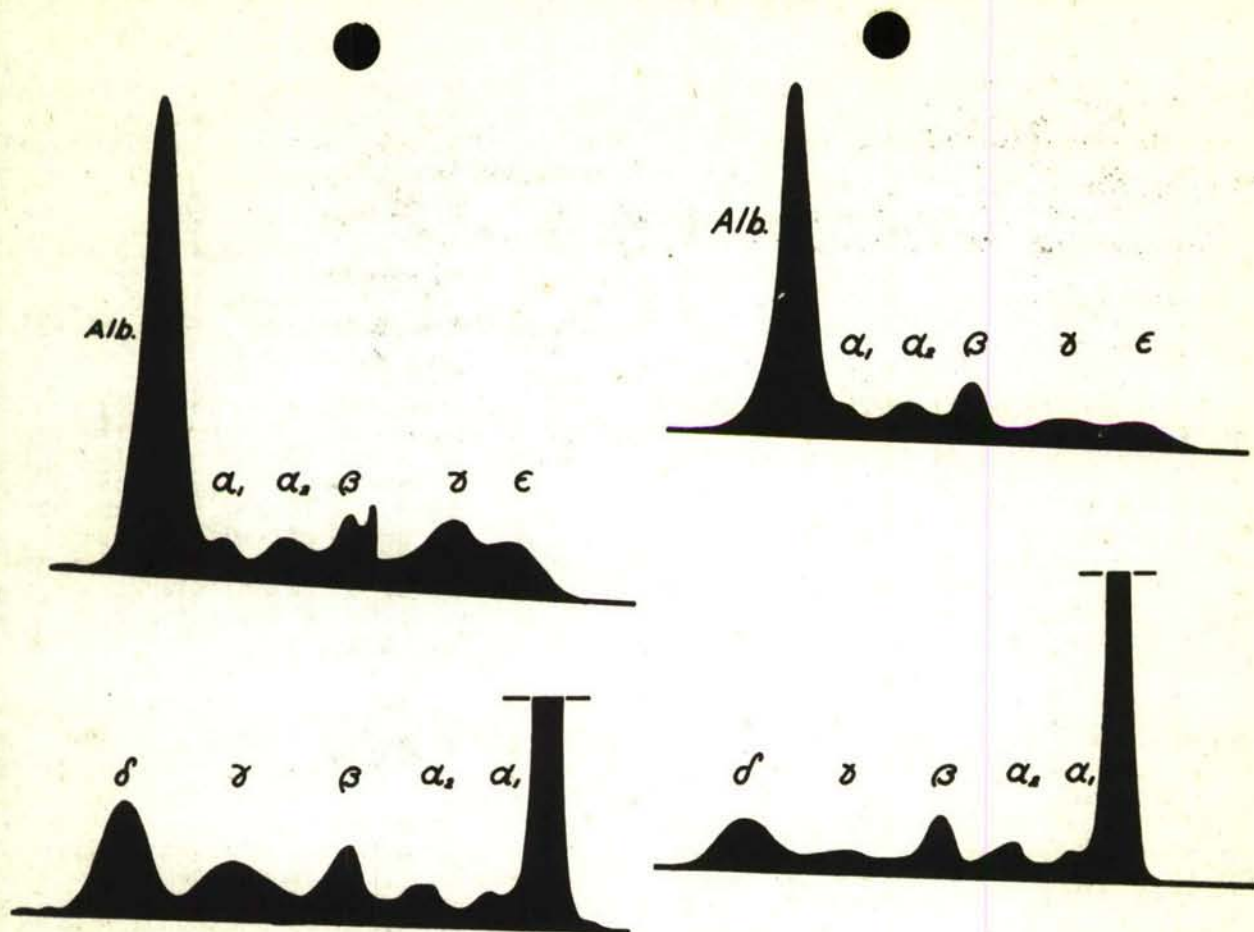


Fig. 14. ELECTROPHORETIC PATTERNS OF serum proteins. Descending boundaries (Top), ascending boundaries (Bottom) of serum proteins which illustrate the situation in normal conditions (left) and at the end of semi-starvation (right).

D. Morphological Changes

The course of weight loss, as an average and in 3 individual examples, are shown in Figures 2, 3, 4, and 5. Both the expected course and the final goal for the percentage weight loss were reasonably well achieved but edema was a considerable problem. On the average the men lost 16.8 kg., which represented 24% of the initial weight. From the specific gravity measurements it was calculated that about 6.5 kg. of this loss was fat, which would suggest that some 10.3 kg. of more vital tissue was lost. This, however, underestimates the true loss of living protoplasm. In the first place any possible demineralization of the bones would not be expected to yield a loss from the skeleton that would be proportionate to that from the rest of the body, although quantitative estimates on this point are not yet complete. Secondly, measurements of the blood volume indicated that the shrinkage in total blood cells was roughly parallel to that of the rest of the body but that the plasma volume was only slightly diminished. The net effect was to produce a total blood volume loss smaller than in proportion to the total weight loss. Finally, there was an important increase in hydration of the body revealed not only by visible edema but more exactly by estimates of the "thiocyanate space" or extracellular fluid volume. At the end of starvation the extra-cellular fluid volume averaged about 34% of the body weight, indicating a rise of about 56% in this compartment. In terms of weight this

excess fluid represents a correction of about 6.5 kg. (or 14 lbs.) which should be subtracted from the body weight. Unfortunately, there is no estimate of intracellular water, but the hydration of the actual cells is generally considered to be relatively stable and no important correction would be expected in this direction.

The changes in the major compartments in the body are portrayed in Figure 12. Assuming the skeleton to be substantially constant, we find the body "tissue" apparently decreased to 18.0 kg., from an initial average of 30.5 kg., a loss of 41%. In this "tissue" represents everything except fat, bone, blood and interstitial fluid.

The means of estimating the shrink of the several tissues of the body are, short of methods only applicable in animal studies, necessarily very limited. The circumferences of the arms and legs showed marked decreases comparable to the reduction in total body weight. As expected, measurements between bony landmarks were essentially unvarying. It is significant, however, that the abdominal girth did not decrease on the average and, in some individuals, was actually larger at the end of starvation than at the start. It must be presumed that this points strongly toward ascites or edema of the abdominal viscera or both. Numerous examinations failed to disclose free fluid in the abdomen or chest in any subject but the methods are anything but sensitive. The significance of the slight fall in "vital capacity" of the lungs is debatable.

The heart was consistently and markedly reduced in size by the starvation. This change was clearly evident by the middle of the starvation period and became progressively more pronounced. Two typical cases are shown in Figures 19 and 20. While the measurements are not completed it appears that the total heart size shrank more than in proportion to the body weight, perhaps as much as the calculated "tissue" change mentioned above. The uncertain element of the residual blood volume in the heart must be recognized but in any case a substantial and probably very large loss of actual cardiac tissue was sustained.

Anemia was roughly proportional to body weight loss. The blood hemoglobin concentration and the blood cells as % of the whole blood both decreased about 22%. The color index was practically unchanged and the red cell counts indicated a similar degree of anemia to that estimated from the hemoglobin measurements.

E. Metabolism and Body Chemistry

Measurements of the basal metabolism before starvation gave values averaging 11.8% below the Mayo Clinic "standard" normal average but this conforms to all experience with normal subjects in this laboratory. During starvation the basal metabolism steadily declined to reach a final average of -39.3% on the Mayo scale. In terms of actual cc. of oxygen used per minute the reduction was 38.7%. This is very close to the calculated percentage reduction in weight of living protoplasm. It will be noted that there was also a slight fall in body temperature.

The metabolic cost of work was not markedly affected by starvation and at most only a trivial change in the efficiency of muscle metabolism could be suggested. This is indicated in Figure 17 where the relation between body weight and oxygen consumption during treadmill walking are shown for the start, the mid-point and the end of starvation.

A number of facts show that there were changes in metabolic details as well as in the total amount. Lactic and pyruvic acids in the blood in rest rose by 9.4% and 28.6% respectively. These changes are considered not to be indicative of thiamine deficiency since the thiamine intake was relatively good and the urinary excretion of this vitamin and of its component pyrimidine ("pyramin") did not approach the deficiency level. In standard work the blood sugar fell and the respiratory quotient rose. The former effect may reflect a diminished capacity to maintain the free sugar level in the face of the demands of work.

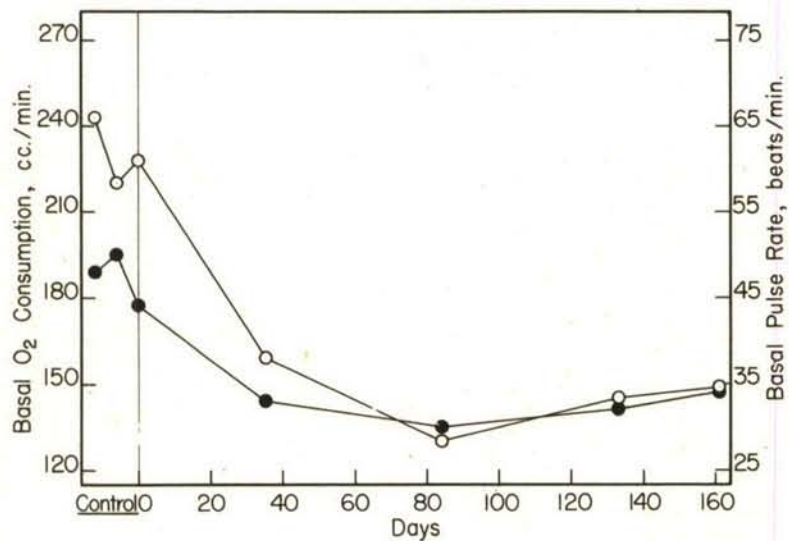
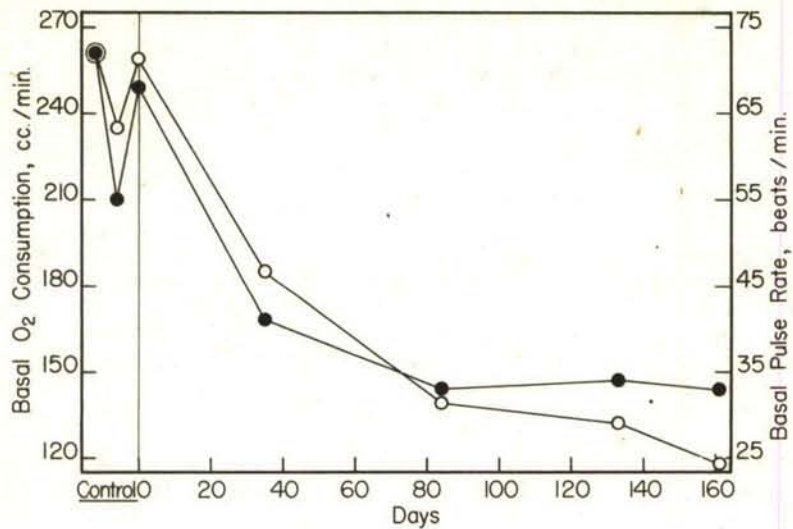


Fig. 15. BASAL METABOLISM AND PULSE RATE. The open circles represent values of the basal oxygen consumption in cc. per minute and the closed circles, basal pulse rate in beats per minute. Subject No. 105 is on the top and subject No. 129 on the bottom.

The change in respiratory quotient is capable of several interpretations. A relative exhaustion of fats for metabolism could be suggested. Perhaps a more likely explanation is that the work became more difficult and there was simply the usual rise in R.Q. as the severity of work is increased. The urinary excretion of creatinine did not increase but actually fell to a significant extent. There was, however, an increased excretion of riboflavin which may reflect tissue destruction and atrophy.

F. The Heart and Circulation

We have mentioned the reduction in heart size. This striking change was at least equalled by the profound decline in heart rate. The initial "control" rates in rest were relatively low but the average values of 35 and 37 for the middle and end of starvation are startling. A number of men consistently had pulse rates of less than 30 and 24 was the average for one man. There was a slight fall in both systolic and diastolic blood pressures and a more substantial drop, amounting to 16.9%, in the pulse pressure. To these general indications of a depressed circulation we may add the fact that the pulse wave velocity (to the antecubital fossa) was diminished in starvation.

The analysis of the electrocardiograms disclosed numerous changes. There were no signs of heart block nor indications of disturbed conduction. The sinus rhythm was considerably less variable than before starvation, and this decreased arrhythmia was both absolute and relative. Special experiments with deep breathing showed that respiratory arrhythmia was diminished. Both the Q-T interval and the duration of mechanical systole (from stethocardiograms) were prolonged absolutely and were decreased in relation to the R-R interval, i.e. as measured by the value of the "constant", K , in the equation: $K = QT/(RR)^{1/2}$.

A conspicuous change in practically all records was the progressive reduction in potentials in all leads. This was true of the P-wave and all of the QRS complex, as well as the T-wave. The decrease in T_1 was considered especially significant. The electrical QRS and T axes systematically and progressively shifted in the direction of an increased right axis deviation.

These changes in the heart might suggest a progressive cardiac weakening or impending failure. It should be pointed out, however, that protective adaptations were probably involved and that, relatively, the cardio-circulatory functions were rather well maintained, at least in rest. Although some cyanosis was almost constantly present and a sensation of coldness was a prominent complaint, it is significant that the venous pressure was actually decreased below normal and the heart rate in both work and recovery was unchanged or decreased. Another indication of the relative lack of cardio-circulatory impairment was the favorable response to postural (tilt table) tests. The "Crampton blood ptosis" score was practically unchanged but perhaps of greater significance is the fact that even the former "fainters" no longer fainted after some months of semi-starvation. On the other hand "blackout" on rising suddenly was a rather frequent complaint and there were enough cases of spontaneous syncope to be troublesome. These of course may not have been related to a general circulatory weakness; there was little progression in the frequency of syncope or giddiness after the first 3 months.

The cardio-circulatory functions cannot be discussed without reference to the blood volume. There was a loss of about one fourth in the total circulating hemoglobin but this was partly offset by a rise in plasma volume so the total circulating blood declined less than 10%. In terms of volumes per kg. of body weight, the blood cells were substantially constant while the plasma and total blood volumes increased markedly.

The maximal oxygen transport in severe work decreased on the average 41.5%; this amounts to a 23% reduction per kg. of body weight. If we assume that under the conditions of measurement of the maximal oxygen transport that neither arterial nor venous saturations were changed significantly, then it would appear that in work the actual amount of blood circulated per kg. of body weight was

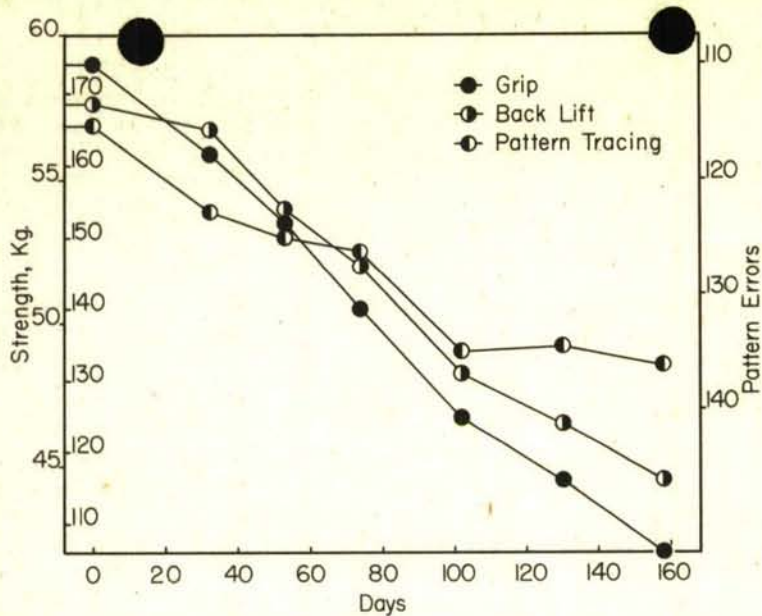


Fig. 16. STRENGTH AND COORDINATION. Grip strength, back strength, pattern tracing errors (number of contacts), average of 34 subjects.

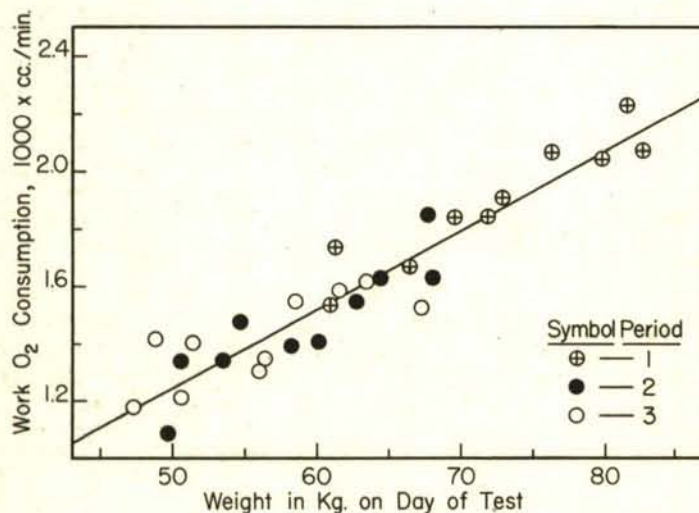


Fig. 17. THE OXYGEN COST OF WORK. Body weight in kilos plotted against the oxygen consumption in liters while walking on the treadmill at 3.5 m.p.h. and 10% grade. The values represent ten men who were studied during the control period (period 1), 12 weeks of semi-starvation (period 2), and 24 weeks of semi-starvation (period 3). The product moment and correlation is 0.94 and the equation of the line is $O_2 = 27.38W - 118.3$.

nearly the same in semi-starvation as before. This would follow from the fact that the blood hemoglobin concentration was, as noted, decreased by 22%. Following the same line of argument, it would seem that the actual amount of blood circulated per unit of "active" tissue must have been increased in work since, as noted previously, the loss in "active" tissue amounted to something like 41%.

G. The Respiration

The maximal oxygen transport is a combined measure of circulatory and respiratory functions, though the latter is not generally the limiting factor. A disequilibrium between circulation and respiration was shown in a reduction in respiratory efficiency both in rest and in work. In severe work the amount of oxygen removed per liter of expired air declined by 21.9%.

It is of interest that the "vital" capacity of the lungs declined slightly though one would suppose the actual thoracic space would be increased by the shrinkage of the heart and the general disappearance of fatty tissue. A weakening of the diaphragm and the intercostal muscles would seem a reasonable explanation; certainly there were no signs of pulmonary congestion or edema. The respiratory rate was little altered in most cases but the depth of respiration diminished progressively. Inspection of the respiratory tracings from metabolism tests suggests an increased variability of depth of respiration but the detailed analysis of the character of the respiration is not complete as yet.

H. Capacity for Physical Work

Ordinary observation showed that the capacity for physical work was much impaired and the maximal oxygen transport measurements showed the circulatory-respiratory limitations of the semi-starved man. The brief endurance capacity for brief effort was shown to be reduced strikingly in tests involving running on the treadmill to complete exhaustion. Compared with an initial average endurance of 245 seconds, the final average was only 51.9 seconds. The validity of this measure was proved in many ways; actual collapse occurred not infrequently. Scoring devices such as that proposed by the Harvard Fatigue Laboratory likewise showed a great but somewhat less marked deterioration. The difficulty of using such a scoring system in which heart rate is one item is well shown in the starving man who seems to be incapable of developing an extreme tachycardia even at the moment of collapse.

The behavior in these maximal exertion and endurance tests on the treadmill was illuminating. Ordinarily approaching exhaustion is heralded by swaying, pounding of the feet and gradual loss of ground by the whole body. In the starving men, however, the body leans forward more and more and the subject is unable to pick up his feet so that he is in imminent danger of falling face down. The picture is one of pure muscular weakness.

I. Strength, Speed and Coordination

In view of the many indications of general muscle atrophy it is not surprising that simple strength was considerably reduced. Both grip strength and back-lift strength were reduced about 30%. These losses were, however, less marked than the changes in endurance and again confirm our general finding that strength is relatively resistant to change as compared with endurance. There were no indications of the development of specific muscle weakness; the whole muscular system seemed to be affected in much the same way.

Speed tests were surprisingly little affected by semi-starvation. Tapping speed, gross body reaction time and the ball-pipe test, which has a large speed component, all responded to about the same extent, with reductions of 5.4 to 7.5%. The maximum speed of a single large movement, as measured in a special "kick test" developed here, may have been more strikingly reduced.

Coordination showed somewhat more but still no extreme deterioration in semi-starvation. Pattern tracing was about 17% less well done than before

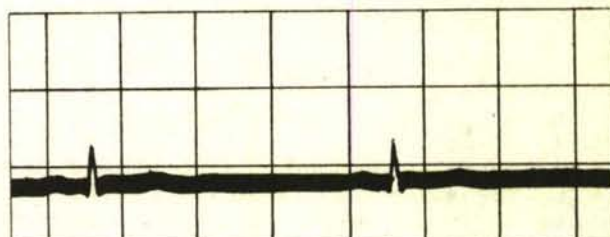
Before



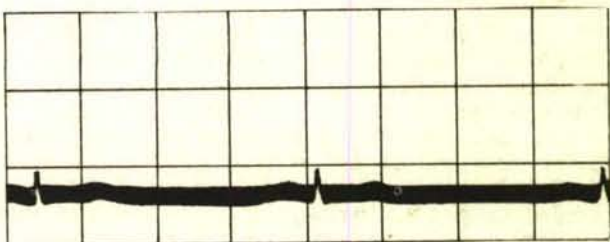
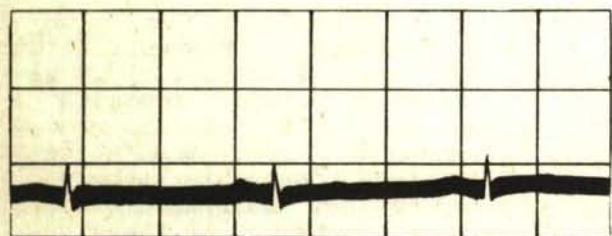
End



Lead I



Lead II



Lead III

Fig. 18. THE THREE STANDARD LEADS OF THE ELECTROCARDIOGRAM
of subject No. 108 taken before and at the end of six
months of semi-starvation.

starvation, whether measured by the total number of errors or by the total duration of all errors. While these changes are not insignificant they are relatively small in view of the sensitivity of these tests to many debilities. The body sway (ataxiometer) decreased by 8.9%, indicating a good maintenance or even slight improvement in this measure of postural coordination.

J. Sensory Functions

There was little or no change in any of the visual functions measured. The visual acuity remained constant at low illumination and decreased to a trivial extent at high illumination. The flicker fusion frequency showed a similar very slight deterioration.

Auditory acuity improved in semi-starvation at every sound frequency from 128 to 8192 double vibrations per second and this improvement was statistically significant. The old saying that hunger sharpens the senses proved to have literal accuracy so far as hearing is concerned. Associated with this change there was a frequent report from the men that loud noises or music were unusually distressing. It is possible that this change was in part responsible for the general cessation of loud talking among the group.

K. Intellective Functions

A very considerable effort was devoted to the estimation of intellective functions in both power and speed tests. The fact that the men in this group initially showed unusually high scores suggested that deterioration might be easy to detect. By and large, however, none of the intellective tests showed any appreciable response to semi-starvation. This result might seem at variance with the subjective statements of the men that in general they felt a decline in intellectual power. On closer examination, however, it appeared that the subjective belief reflected primarily mental lethargy, lack of ambition and general depression. Apparently the mental ability remained untouched but the will to use it declined except under the special stimulus of test situations.

Personality

Simple observation showed that semi-starvation works profound changes on personality, attitude, social behavior and all those relatively intangible items that go to make up what is popularly referred to as "personal psychology". We have already mentioned the development of an overwhelming preoccupation with food and related subjects such as agriculture, gardening, dietetics, gastronomy and rural economy. This interest was not permanent in all men, or at least did not continue to be increasingly manifest. Some passed through a stage of excessive food interest and then apparently rebelled against their acquiescence to this domination of an "animal instinct". Several of these men at times became almost violently irritated by wishful discussions of food.

An important development was an increasing tendency to introversion. Social contacts became "too much trouble," "too tiring," and just plain "dull". Sex interest evaporated rather early and physical lethargy ruled out many forms of extraverted behavior. Ordinary conversation and discussion were limited by the strong tendency of each man to talk chiefly about his personal symptoms, weight and functional peculiarities. It is realized that the ever-present personal restrictions and awareness of the experiment would naturally lead toward hypochondriasis and self-preoccupation, but this factor is by no means adequate to account for the changes in this group. Other groups have been maintained here as "guinea pigs" for long periods of time without manifesting anything like the degree of withdrawal and self-interest exhibited by these semi-starvation subjects.

The physical apathy observed may be readily explained as a protective adaptation to conserve calories. In view of the fact that many mental activities actually involve some physical exertion (e.g., writing, speaking, going to the library) the mental apathy observed here could be interpreted in part as

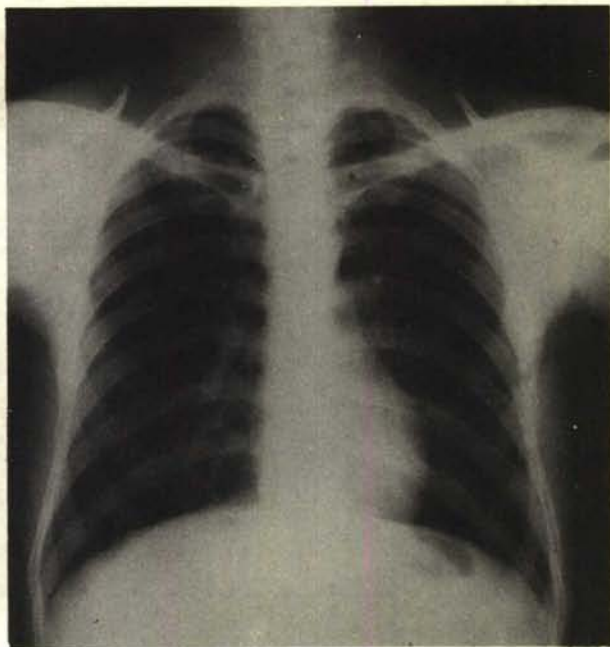
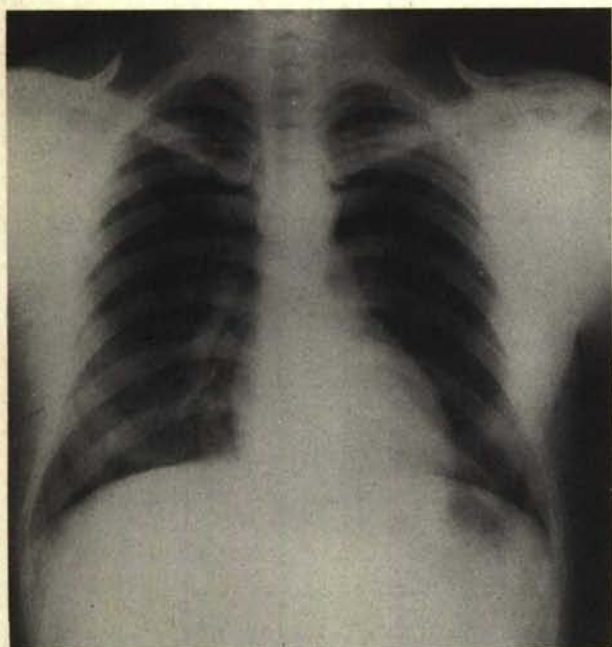


Fig. 19. TELEROENTGENOGRAMS of subject No. 120 taken before and at the end of six months of semi-starvation illustrating the decrease in heart size accompanying semi-starvation.

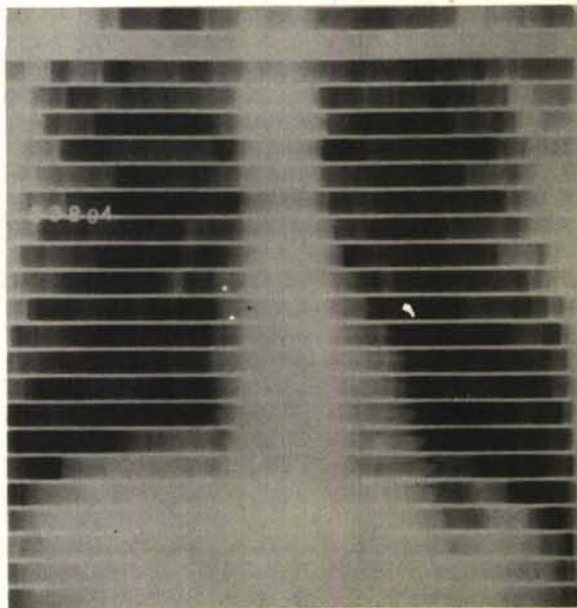
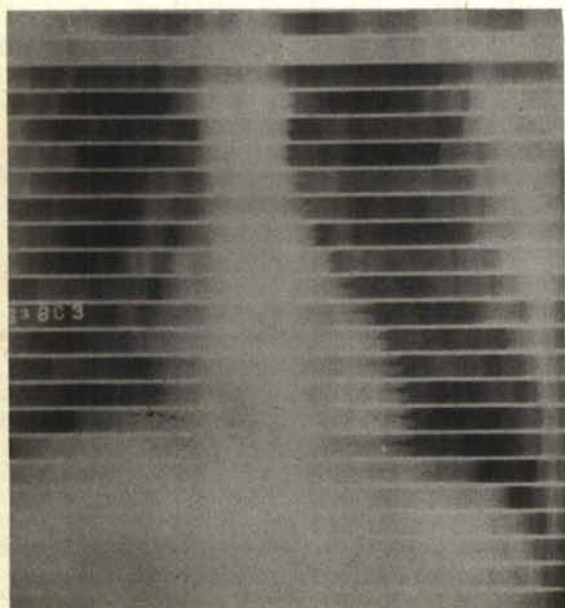


Fig. 20. ROENTGENKYMGRAMS of subject No. 104 taken before and at the end of six months of semi-starvation illustrating the changes in heart size and excursions of the heart border which are the result of six months semi-starvation.

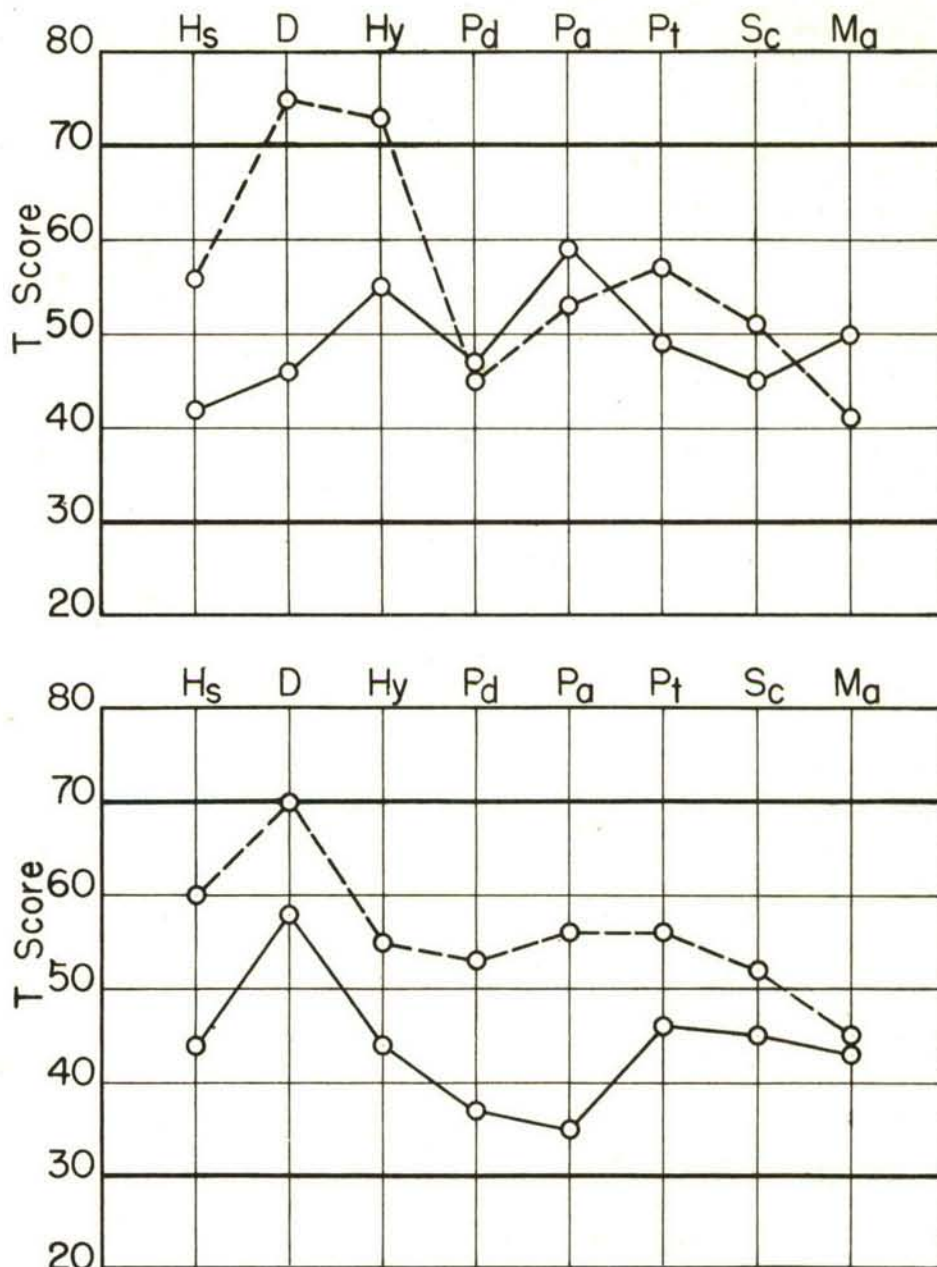


Fig. 21. PERSONALITY. Profile of the Minnesota Multiphasic Personality Inventory. Note that for each scale the average normal score is 50 with a standard deviation of 10. The scale abbreviations are: Hypochondriasis, Hs; Depression, D; Hysteria, Hy; Psychopathic deviation, Pd; Paranoia, Pa; Psychasthenia, Pt; Schizophrenia, Sc; and Hypomania, Ma. Solid line = control; broken line = end of semi-starvation. A. Subject No. 101 before and at the end of semi-starvation. B. Subject No. 129 before and at the end of semi-starvation.

another aspect of this tendency to conserve energy. It seems unlikely, however, that this is the whole explanation.

There were many indications, besides subjective analyses and reports supplied by the men, of a heightened irritability. Expressions of annoyance, disgust and anger became increasingly frequent as starvation progressed but they did not progress to outright violence. Many men reported that on such occasions they had urges to violence, either physical or verbal, but these impulses did not overcome their self control and restricting apathy.

Analysis of the results with the Minnesota Multiphasic Personality Inventory showed many pronounced changes, almost always in the direction of the psychoneurotic. The depression, hypochondriasis and hysteria scores increased significantly and, in many cases, to extents as marked as are encountered in psychoneurotic patients. Much less prominent changes were observed on the psychopathic scales such as the schizophrenia or paranoia scores but the scores in all scales tended to rise (cf. Fig. 21). The Rorschach test results are now in the course of analysis.

VI. MISCELLANEOUS OBSERVATIONS AND PROBLEMS

A. Edema

The prominence of edema has been noted. Of considerable interest is the fact that very substantial relative and even absolute increases in the interstitial fluid volume were indicated even when visible and palpable edema was not demonstrated. The estimates of extracellular fluid volume, corrected for the plasma volume, were taken to be the measure of the interstitial fluid volume. Careful and rather extensive analysis of the thiocyanate dilution method used indicated that this is at least a reasonably reliable, i.e. repeatable, procedure and the changes observed should be valid even though question may attach to the absolute values. Control levels were validated by comparison with results in the literature and by measurements made on other non-starving subjects.

All sources of information agreed in indicating an increase in hydration in these men. The relatively enlarged plasma volume may be noted. There was no information as to whether the hydration of the tissue cells was changed. The appearance of frank edema almost seemed to be more or less accidental and certainly gave a very incomplete picture by itself. The appearance of edema was variable between individuals and even in the same individuals. It appears that the clinical appearance of edema was an insensitive and relatively unreliable index of the state of actual hydration as well as of the state of nutrition.

The mechanism involved in the production of edema and increased interstitial and plasma volume is puzzling. Reductions in plasma protein or of the albumin fraction were by no means adequate to account for the effects on the basis of simple reduction of colloid osmotic pressure. Nor was it possible to explain the phenomenon in terms of changed hydrostatic pressure. The venous pressure did change significantly but in the opposite direction to that required on the basis of the ordinary theory promulgated by Starling and generally accepted since the work of Schade and Claussen, Verney, Krogh and Nakazawa and others. On the tissue side of the vascular membranes we may note that a decreased tissue tension or turgor could not possibly account for more than a small fraction of the force required to bring out and hold extra fluid from the blood stream. We do not have information on the colloid osmotic pressure of the interstitial fluid itself nor on the permeability of the capillary membranes. At present it would appear that the explanation for the edema and increased hydration must involve, in part, alterations in these factors, particularly the capillary membranes. Another but less likely explanation for the apparent increase in thiocyanate space would be that the tissue cells, or some of them, lost part of their normal impermeability and became accessible to extra fluid or at least to thiocyanate. We suggest that these findings demand a careful re-examination of the whole edema problem and the theory of its mechanism. Such a re-examination should include consideration of the control of hydremia.

B. Dental Effects

The periodic examinations of the teeth and gums were surprisingly negative. The dental examiners reported that in no cases were there significant or substantial changes and this was further borne out by the detailed examination of the dental X-rays. Neither the development of old caries nor the incidence of new caries indicated anything but the expectations which would apply to a normally nourished group of young men. Bleeding, inflamed, swollen or sore gums did not develop. We have noted that there was a suggestion in some men of increased sensitivity to firm pressure at the bases of the interdental papillae. The meaning of this is obscure.

C. Specific Vitamin Nutrition

Much interest is devoted to the question of vitamin nutrition in famine states. Obviously the problem must assume very different aspects in different areas of the world where different diets would be used in famines. In the far East the reliance on polished rice naturally leads to susceptibility to beriberi whereas in Europe the tendency to depend on wheat, rye and other cereals and to use more low extraction flours and whole grains in famines makes a very different picture. Likewise, in Europe, famine times ordinarily see the consumption of relatively large amounts of potatoes and cabbages which provide significant amounts of ascorbic acid so that the scurvy problem might not arise.

In the studies here the evidences for vitamin deficiencies seemed to us to be extremely meager. Laboratory methods for appraising status with regard to thiamine, riboflavin and ascorbic acid did not indicate any deficiency in these vitamins. The clinical methods are highly debatable on details for the establishment of the lesser degrees of avitaminosis. Certainly no marked deficiencies in any vitamins could be claimed. There were, however, some suggestions, confined to gross appearance of the skin and mouth, that specific effects of lack of certain vitamins might be playing a role. The best case could be made for Vitamin A in this regard but consideration of other evidence makes this interpretation doubtful. There was no doubt that the skins were roughened, dry and frequently showed follicular keratosis and xerosis of mild degree. Such conditions are often seen in vitamin A deficiency but are scarcely pathognomonic. Skin biopsies showed smaller histological changes than expected from the gross appearance and were certainly insufficient to warrant a conclusion as to avitaminosis A. We must also note the extensive recent evidence from elsewhere as to the very large body reservoir of vitamin A and the many mouths at zero intake required to produce definite effects.

VII. ORGANIZATION

A. Staff; Assistants and Subjects

The administration of this project was the responsibility of the regular senior staff of the Laboratory of Physiological Hygiene:

Ancel Keys, Director and Professor of Physiology
Ernst Simonson, Associate Professor of Physiology
Henry Longstreet Taylor, Assistant Professor of Physiology
Olaf Mickelsen, Assistant Professor of Physiological Chemistry
Austin Henschel, Assistant Professor of Physiology
Joseph Brozek, Assistant Professor of Psychology
Samuel Wells, Physician
Angie Mae Sturgeon, Administrative Technologist

An important share of the operative responsibility was carried by the other members of the regular staff of this Laboratory:

Erma V.O. Miller, Technologist
Howard Condiff, Technologist
Doris Doedon, Technologist

Mildred Olson, Technician
Doris Fredson, Technician
Lorraine Hertz, Technician

Laura Werner, Technician
Marietta Anderson, Dietitian
Signe Haugen, Dietitian
Nedra Foster, Dietitian
Ersal Kindel, General Mechanic
Lester Erickson, Research Assistant
Nellie Oleson, Laboratory Helper

Betty Krueger, Laboratory Helper
Luella Hong, Secretary
Lucile Fritze, Senior Secretary
Mary Hockman, Stenographer
Lorena Mattson, Stenographer
Lorraine Peterson, Stenographer

A number of non-subject members of the Civilian Public Service Unit here provide invaluable assistance in various phases of the program:

Howard Alexander, Statistician
Harold Guetzkow, Psychologist
W. Jarrott Harkey, Unit Leader
Wm. R. Michener, Clerk
John N. Phillips, Clerk
Arthur Snowden, Physicist
Robert Stevens, Educational Asst.
Glen Fisher, Laboratory Asst.
Walter Carlson, Laboratory Asst.

Joseph Franklin, Psychologist
W. O. Caster, Chemist
Eugene Sunnen, Chemist
Marvin Van Wormer, Bacteriologist
Andrew Gibas, Chemist
Wilbur Held, Cook
Grant Washburn, Asst. Cook
Don Martinson, Asst. Cook
Norris Schultz, Clerk

The subjects are, of course, the core of the whole program, and it is a pleasure to record their whole-hearted cooperation in a role which carries a minimum of glory and ordinary pleasure. These men are:

William F. Anderson, II
Harold Blickenstaff
Wendell Burrous
Edward Cowles
George Ebeling
Carlyle Frederick
Jasper Garner
Lester J. Glick
James E. Graham
Earl Heckman
Roscoe Hinkle
Max M. Kampelman
Samuel B. Legg
Philip Liljengren
Howard T. Lutz
Robert P. McCullagh
Wm. T. McReynolds
Dan J. Miller
L. Wesley Miller
Richard Mundy
Daniel J. Peacock
James Plaughner
Woodrow Rainwater
Donald G. Sanders
Cedric Scholberg
Charles D. Smith
William Stanton
Raymond Summers
Marshall Sutton
Kenneth D. Tuttle
Robert Villock
William Wallace
W. Earl Weygandt
Robert Willoughby
Gerald Wilsnack

Nashville, Tenn.
Chicago, Ill.
Peru, Indiana
Port Ludlow, Wash.
Moylan, Penn.
Nappanee, Ind.
Okuchobee, Fla.
Sugar Creek, Ohio
Madison, Wisc.
Rocky Ford, Colo.
Elizabethtown, Pa.
New York, N. Y.
Philadelphia, Pa.
Chicago, Ill.
Lansdowne, Pa.
Monrovia, Calif.
Salem, Oregon
LaVerne, Calif.
Enid, Oklahoma
Bloomington, Ind.
Richmond, Ind.
Fresno, Calif.
Ft. Worth, Texas
Sherrill, N. Y.
Urbana, Ill.
Merchantville, N. J.
Berea, Kentucky
E. Dearborn, Mich.
Clintondale, N. Y.
Cleveland, Ohio
San Anselmo, Calif.
Clarksville, Mich.
Harrisburg, Pa.
Malverne, N. Y.
Toledo, Ohio

We are fortunate in having the generous help and cooperation of a number of experts in several fields:

Internal Medicine -- Drs. C. J. Watson, C. A. McKinley, Frederick Hofbauer.
Neurology and Psychiatry -- Drs. B. C. Shiele, A. B. Baker.
Radiology -- Drs. Leo Rigler, Pauline Mack.
Dermatology -- Drs. Hamilton Montgomery, O. E. Ockuly.
Gynecology -- Drs. George Rogers, Harold Hume.

B. Housekeeping

All the subjects were resident in the Stadium where we were able to provide comfortable dormitory space, toilet facilities, a large recreation room, study rooms and office for the C.P.S. Unit. All meals were prepared and eaten in Shevlin Hall which is a short walk from the Laboratory.

The University athletic building and the main Library are conveniently close and use of these facilities was provided to the subjects as well as other members of the Unit.

The men of the Unit took care of their own quarters and laundry except for bed linens and towels. The operation of the laundry utility, including washing machines and a mangle, was the responsibility of several men of the Unit.

The furniture was reasonably adequate and "functional". Aside from some items which belong to the Laboratory, the furniture was borrowed from the Selective Service System, from the University, and from various individuals and local churches. A good radio-phonograph and large collection of records were much appreciated. The Unit library, comprising several hundred books and a good magazine file, was in constant use.

C. Study Program

A study program for the subjects was provided and this was planned from the outset as an integral part of the general program. This served several purposes. For the subjects it offered an interesting and profitable use of their time not devoted to purely subject and assistance requirements. For the sponsoring church organizations it provided a means of giving basic and academic training for these men who will devote at least some of their future to church-sponsored work. For the scientific aspects of the starvation study it helped the standardization of activities as well as contributed to the maintenance of morale of the subjects.

The central theme of the study program was relief and social service with special reference to foreign operations. There were regular University courses, special courses for this group taught by faculty members, courses taught by members of the subject and "Overhead" group, lectures and talks by Staff members and by various outside speakers, as well as seminars and group discussions. Particular emphasis was placed on languages (French, German, Spanish, Russian), general sociology, area culture studies, modern history, economics and contemporary politics. Brief informal lecture courses were given on nutrition and on elementary physiology. The men averaged something like 25 hours a week in this study program until the later stage of semi-starvation when all activity diminished. Fairly frequent discussions by the Staff provided information on the progress of the starvation experiment and the scientific relevance of the day-to-day details. Some practical contacts were also afforded with local social service operations.

The study program was directed by Mr. Paul Bowman, whose full-time services were provided by the Brethren Service Committee. Mr. Bowman was assisted by Mr. Robert Stevens. The location of the Laboratory in the midst of the University of Minnesota Campus was advantageous.

D. Contributing and Sponsoring Organizations

Aside from the University of Minnesota as represented by this Laboratory, the initial sponsorship of this starvation-rehabilitation program was given by the Brethren Service Committee of the Church of the Brethren. In this the American Friends Service Committee quickly participated and cooperation was enlisted from the National Service Board for Religious Objectors and the Mennonite Central Committee.

The program was authorized by the Division of Camp Operations of the Selective Service System after endorsement by the Committee of Medical Research of the Office of Scientific Research and Development. The Selective Service System loaned beds, chairs, mattresses, pillows and blankets. A contract providing for participation of the Office of Scientific Research and Development in the support of the project was recommended by the Committee on Medical Research and became operative on July 1, 1945. Negotiations to transfer this contract to the Office of the Surgeon General, U.S. Army, are now under way.

In addition to general sponsorship, the "peace churches" have given important financial support. Substantial financial help has also been given by the John and Mary R. Markle Foundation for Medical Research and by the Home Missions Board of the Unitarian Society. Participation in this work has been arranged for research programs operating in this Laboratory under the sponsorship of the Sugar Research Foundation, Inc., New York, and the National Dairy Council on behalf of the American Dairy Association, Chicago. A considerable part of the cost is carried by the ordinary research and operating budgets of the Laboratory of Physiological Hygiene; University of Minnesota Athletic funds are important in these budgets.

VIII. REHABILITATION

The purposes to be served by a study of rehabilitation from the state of semi-starvation produced here are obvious. This very important phase of the work was planned at the outset and has, at the time of writing (Oct. 15, 1945) progressed very satisfactorily. The subject group was reduced to 32 and these men were placed in equivalent teams on diets differing in calories, proteins and vitamins according to a systematic factorial design. This permits evaluation of the effects of 4 caloric levels and of 2 protein and 2 vitamin levels at each caloric level.

The results of the rehabilitation studies will be reported separately as the results are obtained and analysed.

TABLE I

Representative diets during standardization period.
Caloric values calculated from standard dietary tables.

Date	January 24, 1945		January 30, 1945		February 8, 1945	
	Wt. per person (gms.)		Wt. per person (gms.)		Wt. per person (gms.)	
Food served		Food served		Food served		
Tomato juice	100	Grapefruit juice	100	Vegetable juice	100	
Corn Flakes	30	Bran Flakes	30	Bran Flakes	30	
Sugar	10	Bread	150	Jam	70	
Butter	30	Butter	30	Bread	150	
Bread (white)	150	Sugar	10	Butter	30	
Milk	540	Jam	70	Sugar	10	
Soda crackers	6	Milk	540	Milk	720	
Split-pea soup	125	Vegetable soup	110	Soda cracker	8	
Hamburger	40	Crackers	8	Cream of corn		
Gravy	75	Macaroni and		soup	110	
Potatoes	120	cheese	200	Ground beef	60	
Wax beans	100	Scrambled eggs	60	Gravy	75	
French Dressing	15	Bacon	20	Potatoes	210	
Rice pudding	75	Cabbage	75	Green beans	100	
Swiss steak	50	Sponge cake	30	Apricots	45	
Gravy	75	Orange sauce	30	Lettuce	15	
Squash	100	Beef roast	60	Apple Betty	100	
Pickles	20	Parsnips	100	Pork chops	60	
Apple pie	125	Potatoes (mashed)	200	Peas	100	
		Tomatoes (fresh)	75	Apple sauce	100	
		Mayonnaise	10	Gingercake	60	
		Gravy	75	Sweet potatoes	170	
		Ice cream	75			
		Vanilla wafer	5			
Total Protein	131 gms.		89 gms.		90 gms.	
Total Fat	128 gms.		146 gms.		114 gms.	
Total Calories	3410		3056		3032	

TABLE II

Analyses of diets served during the standardization period.
Protein analyses by the Macro Kjeldahl method.

Date	Gms. protein per day	Date	Gms. protein per day
Nov. 29	96.2	Dec. 29	106.8
Dec. 7	118.9	30	104.8
12	113.4	31	101.3
13	108.0	Jan. 1	95.6
22	124.7	3	112.0
27	119.2	4	105.8
28	113.5	24	102.4
		Average	110.0

Approximate analyses					
Diet	Weight	%H ₂ O	gms. Fat	gms. Ash	Calories
Jan. 16	2196	66.9	119.5	27.0	3397
Jan. 17	2319	68.3	104.1	23.9	3365

Table III

Complete menus for the semi-starvation period.

Breakfast

Menu No. 1		Menu No. 2		Menu No. 3	
Food served	Wt. gms.	Food served	Wt. gms.	Food served	Wt. gms.
Farina (27 gms. dry unenriched farina)	200	Oatmeal (27 gms. dry oat- meal)	190	Pancakes (45 gms. gra- ham flour 50 gms. skim milk 1.2 gms. egg 2.8 gms. sugar 0.9 gms. lard)	100
Jam	20	Jam	20	Syrup	50
Milk	40	Milk	40	Jam	20
Sugar	10	Sugar	10	Applesauce	70
Fried potatoes	150	Fried potatoes	200	Cornbread	110
Jello with dried apples	100	Gingerbread	50	Bread	180
Bread (whole wheat)	180	Bread (whole wheat)	180		

Supper

Food served	Wt. gms.	Food served	Wt. gms.	Food served	Wt. gms.
Fish chowder (102 gms. potatoes 11 gms. onions 11 gms. celery 7 gms. fish 20 gms. milk 7 gms. butter 2 gms. flour)	200	Bean and pea soup (5 gms. dried peas 16 gms. dried beans 15 gms. fresh ham)	185	Potato soup (100 gms. po- tatoes 10 gms. onions 30 gms. skim milk 5 gms. whole wheat bread 25 gms. beef)	250
Spaghetti and meat balls (100 gms. wet spa- ghetti 20 gms. beef 7 gms. oatmeal 5 gms. onions 60 gms. tomatoes)	200	Macaroni and cheese (130 gms. wet macaroni 12 gms. lard 108 gms. skim milk 2 gms. flour 35 gms. American cheese)	255	Stew (90 gms. tur- nips 20 gms. carrots 35 gms. green beans 5 gms. lard 10 gms. onions)	285
Steamed potatoes	150	Rutabagas	40	Steamed potatoes	205
Peas and carrots (38 gms. peas 17 gms. carrots)	55	Steamed potatoes	100		
Cabbage salad (100 gms. cabbage 10 gms. sugar 10 gms. vinegar)	120	Lettuce salad (80 gms. lettuce 10 gms. vinegar 10 gms. sugar)	100		

Table IV

Nutritional Composition of the basic Semi-Starvation Diets

Menu	Wt. gms.	H ₂ O %	Ash gms.	Fat gms.	Prot gms.	CHO gms.	Cal.
I	1862	77.0	21.0	10.2	52.6	344.5	1680
II	1881	73.0	23.9	40.3	46.5	393.4	2122
III	1737	74.0	21.9	16.2	48.1	365.4	1799
Average	1827	74.7	22.3	22.2	49.1	367.8	1867

Menu	Cl as gms. NaCl	Ca gms.	P gms.	Fe mg.	Thiamine mg.	Riboflavin mg.	Niacin mg.
I	13.88	0.59	1.01	36.6	1.14	0.70	22.7
II	13.46	0.97	1.27	30.7	1.56	0.75	19.5
III	9.03	0.73	1.44	22.1	1.17	0.67	20.0
Average	12.12	0.76	1.24	29.8	1.29	0.71	20.7

Table No. V

Results of 24 weeks of semi-starvation. Data on several variables selected for illustration of the individual changes in all 34 men. Column headings C, 12, and 24 refer, respectively, to the values during the control period, after 12-13 weeks, and after 24 weeks of semi-starvation. The heights (Ht.) are given in cm.; Basal Pulse in beats per minute; B. M. R. in percent of value predicted from height and weight (Mayo Standards); Hemoglobin in Grams per 100 ml of blood; Fitness as the score of the Harvard Fatigue Laboratory Test; Strength as the tension developed with the back-lift dynamometer, and Depression as the depression score in the Minnesota Multiphasic Personality Inventory. Further details regarding the data are given in the footnote.

Subject	Age	Ht.	Wgt., Kg.			Basal Pulse			B. M. R.			Hemoglobin			Strength, Kg.			Fitness			Depression		
			C	12	24	C	12	24	C	12	24	C	12	24	C	12	24	C	12	24	C	12	24
1	22	186.7	77.2	63.5	57.0	47	28	29	-17	-36	-40	13.7	12.7	12.6	178	147	141	66	41	17	56	49	60
104	21	176.8	68.1	55.3	51.6	49	34	34	-17	-42	-42	14.6	13.0	12.3	174	143	120	84	35	18	52	68	76
122	21	168.6	65.4	51.6	47.4	56	38	37	-6	-35	-42	15.0	13.2	12.3	174	143	130	70	36	23	54	76	74
111	26	178.4	63.0	51.5	49.1	62	42	39	-8	-32	-41	15.2	13.2	12.8	178	134	122	62	27	13	64	73	90
29	32	179.6	71.1	55.3	53.5	55	42	42	-8	-34	-37	15.3	12.9	11.2	170	101	101	63	10	8	49	69	83
8	23	168.6	64.6	50.4	47.5	49	33	38	-12	-40	-45	15.0	12.6	9.0	157	105	92	70	14	7	57	80	88
19	23	172.5	70.6	56.5	50.4	52	35	38	-17	-39	-46	15.6	12.4	12.4	206	145	122	82	30	9	52	66	56
108	26	170.8	66.9	56.2	54.1	52	38	36	-10	-32	-38	15.5	13.0	12.7	185	147	120	76	30	18	48	58	72
9	22	188.6	72.9	59.8	58.1	48	31	34	-15	-46	-49	14.3	13.7	11.6	193	132	132	90	33	18	58	78	95
22	26	177.8	65.1	53.2	49.4	58	32	36	-13	-28	-45	15.4	14.1	11.7	201	143	120	82	43	22	54	61	64
119	23	177.5	66.3	53.7	49.1	55	44	45	-14	-28	-32	14.8	14.0	12.7	132	111	107	62	41	29	55	64	71
2	24	178.4	73.5	58.5	55.9	61	35	33	-10	-34	-41	15.9	13.0	11.1	117	113	96	44	32	18	51	59	63
20	28	176.5	64.7	52.9	48.0	59	34	41	-10	-29	-34	15.0	13.3	10.6	168	130	105	72	32	6	56	67	104
109	33	188.0	79.3	64.6	59.5	55	36	42	-9	-27	-28	14.0	13.3	11.6	122	103	103	42	34	20	49	50	65
129	24	188.0	65.6	55.6	52.2	47	30	34	-12	-47	-38	14.9	13.3	12.2	-	-	-	45	18	12	47	65	68
101	29	178.0	64.5	53.2	49.7	58	36	34	-15	-38	-42	15.8	13.4	11.8	138	126	103	48	33	8	58	67	72
102	29	179.1	67.9	55.0	51.9	63	42	45	-13	-30	-36	16.3	14.8	12.5	122	101	92	36	27	22	45	52	52
105	26	176	68.7	55.3	51.8	72	33	33	+2	-41	-47	17.3	15.0	10.0	193	151	120	51	33	10	68	70	75
126	26	185.7	83.6	67.8	60.6	44	30	31	-22	-40	-44	14.6	14.3	11.1	180	164	155	49	32	14	52	60	84
23	20	178.8	69.2	54.8	51.4	69	44	47	-10	-30	-31	16.8	12.9	12.9	143	128	109	61	34	27	63	67	72

Subject	Age	Ht.	Wgt., Kg.			Basal Pulse			B. M. R.			Hemoglobin			Strength, Kg.			Fitness			Depression		
			0	12	24	0	12	24	0	12	24	0	12	24	0	12	24	0	12	24	0	12	24
30	25	181.4	68.1	56.6	52.4	60	36	37	-15	-38	-46	15.0	13.0	12.5	149	124	109	65	32	17	57	69	80
232	25	190.5	82.8	67.8	64.4	56	34	45	-17	-37	-35	14.8	12.2	13.3	222	136	153	88	27	22	46	70	78
120	31	172.7	70.8	56.4	51.6	55	41	42	-11	-26	-30	15.8	14.0	12.7	174	153	132	40	29	23	61	81	86
123	26	181.6	64.7	55.1	52.1	53	43	37	-10	-37	-44	13.7	11.7	9.9	151	122	109	78	31	8	52	63	70
130	23	185.4	66.0	50.8	53.6	52	28	27	-16	-40	-48	14.8	13.0	10.9	130	124	99	80	43	21	66	87	93
4	27	174.2	62.0	49.7	47.4	62	31	38	-3	-33	-33	15.4	12.9	12.3	176	138	109	83	47	39	49	59	80
11	26	178.4	66.4	53.8	49.6	53	34	41	-20	-32	-38	15.4	12.9	11.6	122	96	94	48	40	26	67	73	78
26	22	181.6	71.3	57.9	53.1	52	30	30	-10	-40	-40	14.8	13.9	12.6	218	157	147	82	49	35	52	59	64
27	26	178.4	75.2	60.1	55.7	46	32	33	-16	-28	-38	14.2	13.0	11.3	178	130	105	88	41	21	43	54	62
5	28	178.4	80.8	63.2	57.1	60	43	48	-12	-22	-34	15.1	13.0	11.6	-	-	-	26	22	19	48	56	72
112	22	176.3	61.7	50.6	49.0	53	30	41	-12	-36	-28	15.5	13.6	12.0	180	147	143	77	39	28	54	68	70
12	32	192.4	81.0	61.7	63.2	50	33	34	-10	-32	-41	13.2	11.8	10.1	-	-	-	52	34	5	54	60	57
233	21	177.5	75.6	62.6	62.0	38	24	25	-9	-37	-43	14.6	13.0	13.1	206	155	143	92	39	26	51	86	88
127	26	181.6	64.2	51.6	49.3	59	32	38	-6	-35	-39	16.6	13.3	11.7	189	164	136	78	36	19	45	54	68
Mean	25.4	179.7	70.0	56.9	53.2	54.7	37.2	37.2	-11.8	-39.2	-39.2	15.1	13.2	11.8	168.6	132.7	116.4	65.6	18.5	11.5	54.0	74.4	65.7
						34.9			-34.1									33.1					

Footnote

The weights are averages of the daily stripped weights in the following periods: Control, February 5th to 11th, 12 (weeks) May 7th to 20th and 24 (weeks) July 23rd to 29th. The figures for the basal pulse are the average of two items during the control period while the "12" and "24 week" figures represent one observation. The control value of the B. M. R. is the last of three or more trials during this period. The control data on the Fitness test represents the average of the last two of 4 trials during the control period, while the 12-week and 24-week values are the result of only one trial. The control Hemoglobin values again represent the average of two determinations (during the blood volume procedure). The "12 week" value is one determination taken during blood volume procedure (when available) and the "24 week" value was determined on blood drawn from the men in the morning before rising. All the figures for both the back dynamometer and the depression score are the average of two trials separated by some days in each period.

Table No. VI

Sixty-seven representative items of measurements showing the averages during the control period, the "12 week period" and the "24 week period" of semi-starvation. The differences and the percentage differences give the changes during the six-month period of semi-starvation. In all cases a negative sign for the difference indicates deterioration and a positive sign improvement. In those cases where it is still difficult to determine the significance of the change, the value has been put in parentheses. Where the averages are for less than the full group of 34 men the same men are represented in each average. In items 25B and 25C, the "12 week" data are averages of only 12 of the 34 men represented in the control and "24 week" periods. In items 34B, 34C and 34D "M.M.I." refers to the score in the Minnesota Multiphasic Personality Inventory.

Item	No. of men	Control	"12 wk."	"24 wk."	Diff.	%Diff.
1. Basal body wt., kg.	34	70.0	56.9	53.2	-16.8	-24.0
2. Specific gravity of the body	34	1.071	1.084	1.089	-0.018	-1.7
3. Calc. total fat, kg.	34	9.62	4.44	3.08	-6.54	-68.0
4. Thigh girth, cm.	34	47.3	40.5	38.3	-9.0	-19.0
5. Vital capacity, liters	34	5.15	4.92	4.83	-0.32	-6.2
6. Body temp., oral, °F.	34	97.1	95.7	96.8	-0.3	-0.3
7. Basal pulse, beats/min.	34	55	35	37	-18	-33
8. Basal blood pressure, mm.:						
A. Systolic	34	107	99	95	-12	-11.2
B. Diastolic	32	70	68	64	-6	-8.6
C. Pulse Pressure	34	36.6	30.6	30.4	-6.2	-16.9
9. Basal metabolism:						
A. cc. O ₂ /min.	34	229.2	155.2	140.6	-88.6	-38.7
B. as % of Mayo Standard	34	88.2	65.3	60.3	-27.9	-31.6
10. Tilt table test:						
A. Systolic blood pressure tilted	33	110	93	90	-20	--
B. Pulse rate tilted	33	71	56	57	-14	--
C. Crampton score	33	41.2	38.9	38.6	-2.6	-6.3
11. Hemoglobin, Gm/100 ml. blood	34	15.1	13.2	11.8	-3.3	-22
12. Hematocrit. cells % whole blood	34	46.4	39.8	36.6	-9.8	-21.1
13. (A) Blood Volume, liters						
a. Total plasma	16	3257	3206	3541	+284	(+11.5)
b. Total cells	16	2728	2134	2045	-683	(-25.0)
c. Total blood	16	5985	5340	5586	-399	(-6.7)
(B) Blood Volume as ml. per Kg. body-weight						
a. Plasma per kg.	16	45.2	54.2	64.0	+18.8	(+41.8)
b. Cells per kg.	16	38.0	36.1	36.8	-1.2	(-3.2)
c. Blood per kg.	16	83.2	90.3	100.8	+27.6	(+33.2)
14. Plasma protein, gm. per 100 ml.		6.85	6.55	6.12	-0.73	-10.6
15. Tiselius analysis:						
A. Albumin %	2	63.3	70	64	+0.7	--
B. Alpha one globulin % of glob.	2	12.6	11.7	10.8	-1.8	--
C. Gamma globulin % of glob.	2	34.4	30.5	27.6	-6.8	--
16. Blood lactate, rest, mg./100 ml.	8	9.0	11.0	9.8	-0.8	-9.4
17. Blood pyruvate, rest, mg./100 ml.	8	1.12	1.35	1.44	-0.32	-28.6
18. Urine creatinine, gm./day	34	--	1.19	1.01	--	--
19. Urine thiamine, mg./day	34	--	121.4	131.8	--	--
20. Urine "pyramine", mg./day	34	--	135.1	131.8	--	--
21. Maximal O ₂ transport:						
A. liters per minute	7	3.35	2.33	1.96	-1.39	-41.5
B. cc. per kg. body wt.	7	48.2	41.7	37.1	-11.1	-23.0
22. Work resp. effc., cc. O ₂ out/ L. exp. air	7	41.6	35.2	32.5	-9.1	-21.9

<u>Item</u>	<u>No. of men</u>	<u>Control</u>	<u>"12 wk."</u>	<u>"24 wk."</u>	<u>Diff.</u>	<u>%Diff.</u>
23. Harvard Fatigue Lab. Fitness Test:						
A. Score	34	65.6	33.1	18.5	-47.1	-71.8
B. Time of run (seconds)	34	245.0	105.7	51.9	-193.1	-79
24. Aerobic work, pulse rate:						
A. In work	34	134	129	134	0	0.0
B. In recovery	34	106	98	96	-10	-9.4
25. Aerobic work, metabolism:						
A. Blood sugar	34	71	62	60	-11	-16
B. R.Q.	34	0.87	0.92	0.94	-0.06	-6.7
C. O ₂ consump., l./min.	34	1.813	1.468	1.348	-0.465	-25.6
D. Work cost, Cal./min. x kg.	34	0.1106	--	0.1121	0.0014	+1.3
26. Gastric emptying time, min.	18	175	--	226	-51	-29.1
27. Number of dental caries	34	5.6	--	6.6	1	--
28. Strength:						
A. Grip strength, kg.	34	59.1	47.3	42.3	-16.8	-28.4
B. Back lift strength, kg.	31	169	133	118	-51	-30.2
29. Speed and coordination:						
A. Pattern tracing, errors	34	115.2	134.7	135.4	-20	-17.5
B. Pattern tracing, time	34	9.18	10.4	10.7	-1.52	-16.6
C. Reaction time, 0.01 sec.	34	42.2	44.5	45.6	-3.4	-7.5
D. Ball pipe test	34	75.2	72.7	71.7	-4.1	-5.4
E. Tapping speed	34	66.4	63.0	62.7	-3.7	-5.6
30. Postural instability	34	76.2	72.3	69.7	+6.8	+8.9
31. Visual acuity, threshold angle						
A. High illumination	34	0.68	0.71	0.70	0.02	-2.9
B. Low illumination	34	2.1	2.1	2.1	0	0
32. Auditory acuity:						
A. at 128 d.v./sec.	34	-4.83	--	0.02	4.85	--
B. at 512 d.v./sec.	34	-0.37	--	3.83	4.20	--
C. at 2048 d.v./sec.	34	-1.21	--	4.33	5.54	--
D. at 4096 d.v./sec.	34	-5.12	--	0.15	5.27	--
E. at 8192 d.v./sec.	34	1.05	--	3.52	2.47	--
33. Intellectual functions						
A. The C.A.V.D.	34	144	143	142	-2	-1.4
B. Factor battery						
1. Flags, spatial relations	34	58	57	59	1	+2
2. Word fluency (1st letter recall)	34	45	47	47	2	+4
3. Perceptual speed (number comp.)	34	44	41	45	1	+2
4. Memory (word-No. comb.)	34	27	28	28	1	+4
5. Multiplication	34	43	42	43	0	0
6. Reasoning letter series	34	15	16	15	0	0
34. Personality						
A. No. complaints/subject	34	6.2	15.1	21.3	-15.1	-243
B. Depression (M.M.I.)	34	54.0	65.7	74.4	-20.4	-37.8
C. Hypochondriasis (M.M.I.)	34	45.7	59.0	63.3	-17.6	-38.5
D. Hysteria (M.M.I.)	34	58.7	66.0	70.3	-11.6	-19.8